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(12) **United States Patent**  
**Thigpen et al.**

(10) **Patent No.:** **US 9,086,348 B2**  
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(54) **DOWNHOLE ACOUSTIC EMISSION  
FORMATION SAMPLING**

USPC ..... 73/152.01, 152.03, 152.28, 81, 573;  
367/25  
See application file for complete search history.

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(73) Assignee: **VAREL EUROPE S.A.S.**, Pau (FR)

(\*) Notice: Subject to any disclaimer, the term of this  
patent is extended or adjusted under 35  
U.S.C. 154(b) by 918 days.

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(22) Filed: **Jul. 29, 2011**

(65) **Prior Publication Data**

US 2011/0286304 A1 Nov. 24, 2011

**Related U.S. Application Data**

(63) Continuation-in-part of application No. 13/152,126,  
filed on Jun. 2, 2011, now Pat. No. 8,596,124, which is  
a continuation-in-part of application No. 12/963,913,  
filed on Dec. 9, 2010, now Pat. No. 8,365,599, which

(Continued)

(51) **Int. Cl.**  
**G01V 1/40** (2006.01)  
**E21B 47/14** (2006.01)

(Continued)

(52) **U.S. Cl.**  
CPC ..... **G01N 3/44** (2013.01); **E21B 47/101**  
(2013.01); **E21B 49/00** (2013.01); **G01N 29/14**  
(2013.01);

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(58) **Field of Classification Search**  
CPC ..... G01N 3/44; G01N 29/14; G01N 29/223;  
G01N 2203/0658; G01N 2203/0623; G01N  
2291/02827; G01N 2291/0232; E21B 49/00;  
E21B 47/01

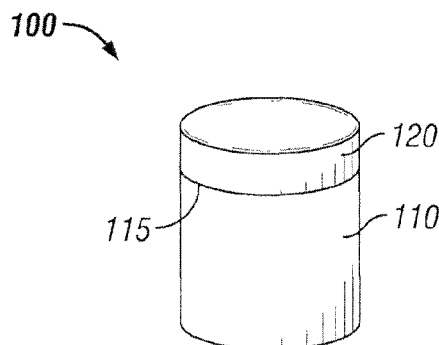
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(57) **ABSTRACT**

A method, system and apparatus for testing properties of a rock formation surrounding a wellbore in situ. The apparatus includes a tool body, one or more indenters, and one or more acoustic sensors. The body includes an outer surface that defines one or more cavities therein. Each cavity extends into the body. Each indenter is positioned within a corresponding cavity and is positionable into an operating position and a non-operating position. The acoustic sensor is positioned within the cavity and adjacent to the indenter. The indenter is positioned at least partially beyond the outer surface when in the operating position. The acoustic sensor senses one or more acoustic events occurring when the indenter is in the operating position. The apparatus is inserted into the wellbore. Once inserted, the indenter applies a load onto the rock formation causing cracking and the sensor receives the generated acoustic transmissions. The transmissions are analyzed.

**17 Claims, 25 Drawing Sheets**



**Related U.S. Application Data**

is a continuation-in-part of application No. 12/769,221, filed on Apr. 28, 2010, now Pat. No. 8,397,572, which is a continuation-in-part of application No. 12/754,784, filed on Apr. 6, 2010, now Pat. No. 8,322,217.

**(51) Int. Cl.**

**G01N 3/44** (2006.01)  
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**G01N 29/22** (2006.01)  
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**E21B 49/00** (2006.01)

**(52) U.S. Cl.**

CPC ..... **G01N 29/223** (2013.01); **G01N 2203/0623**  
 (2013.01); **G01N 2203/0658** (2013.01); **G01N**  
**2291/0232** (2013.01); **G01N 2291/02827**  
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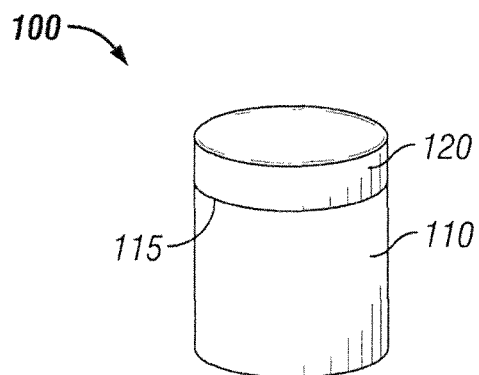


FIG. 1

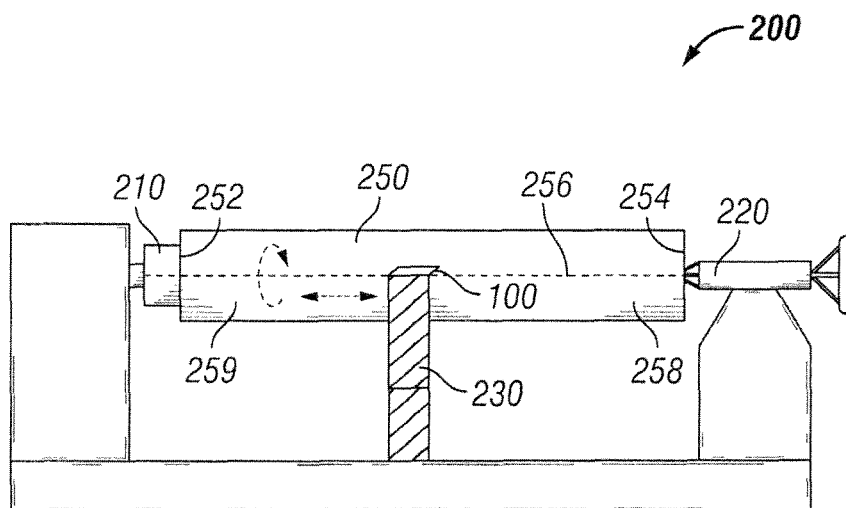


FIG. 2

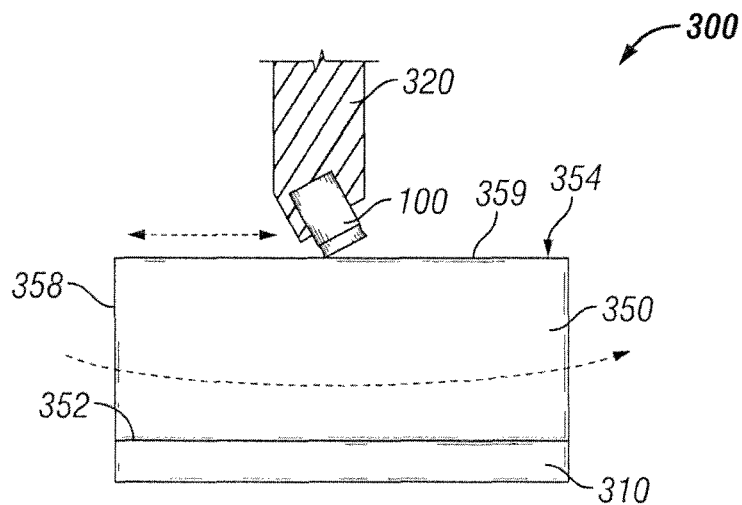


FIG. 3

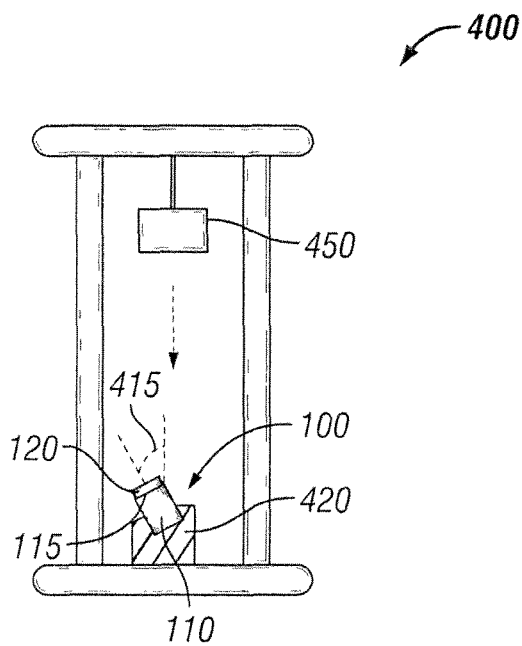


FIG. 4

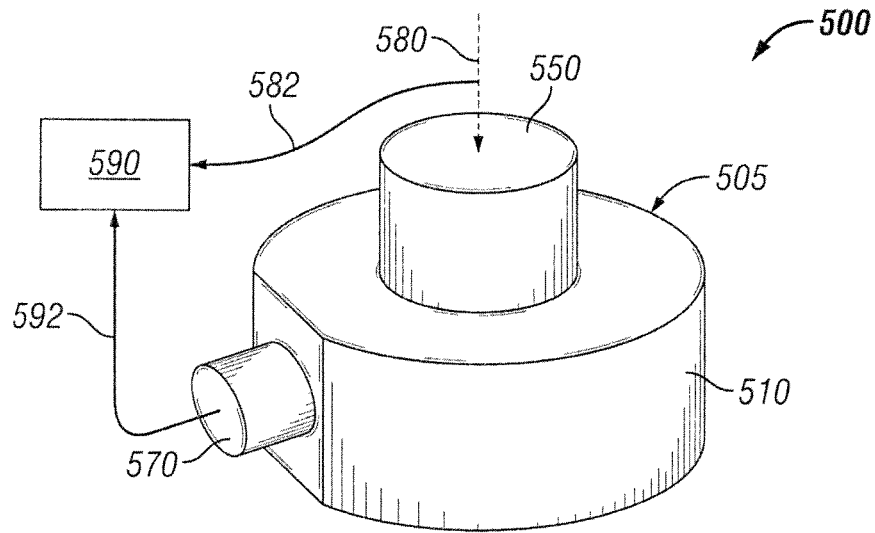


FIG. 5

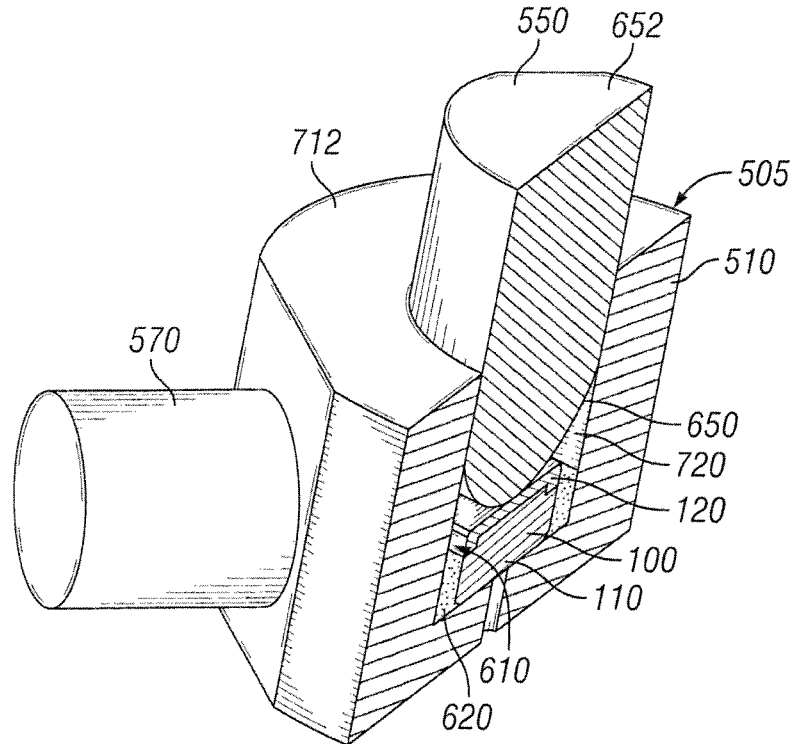


FIG. 6

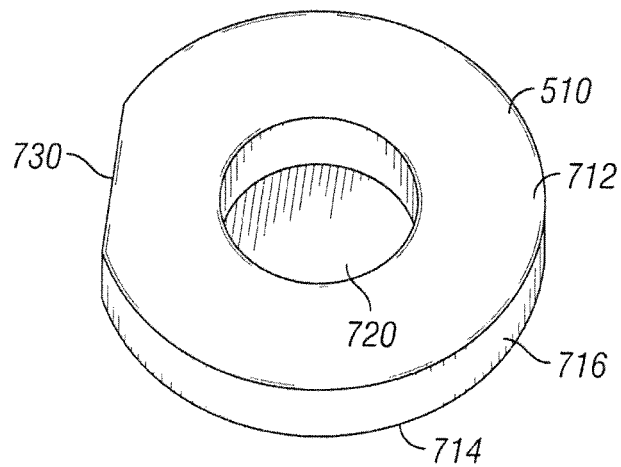


FIG. 7

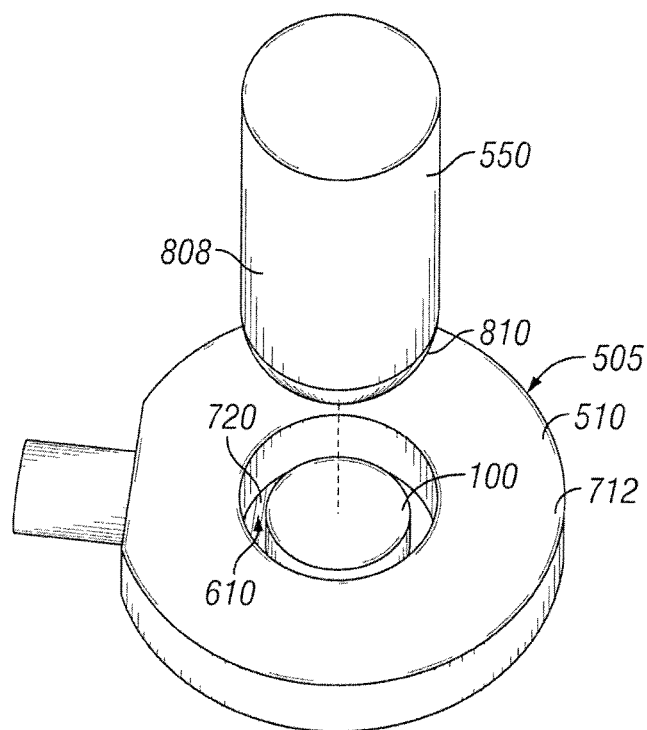


FIG. 8

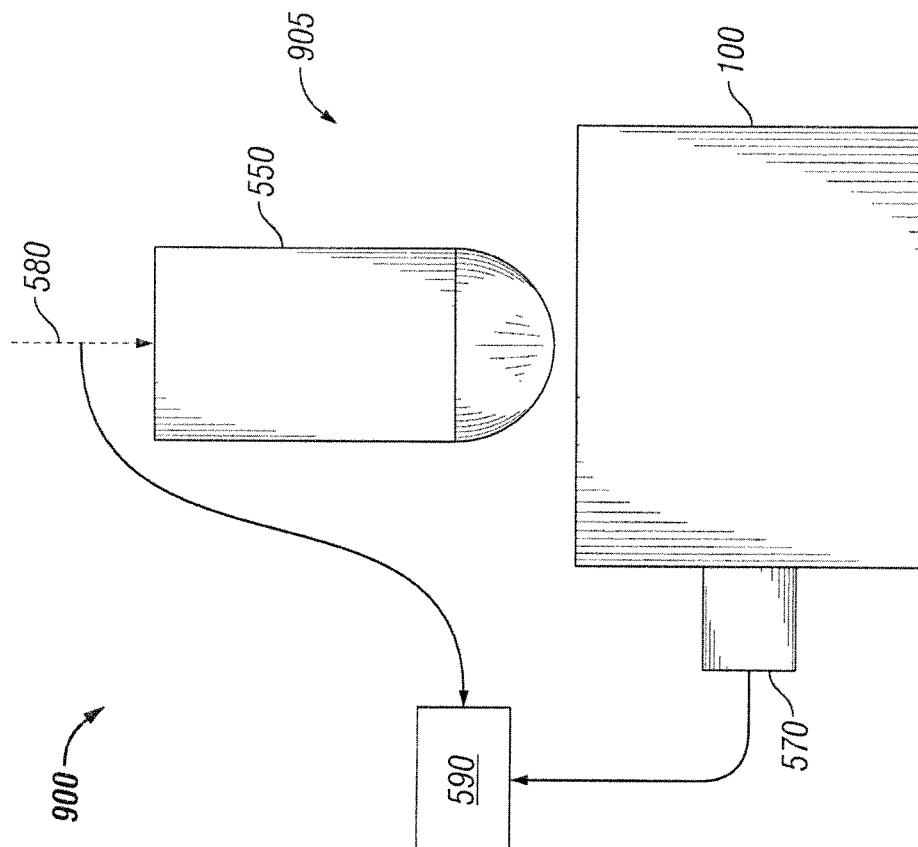


FIG. 9

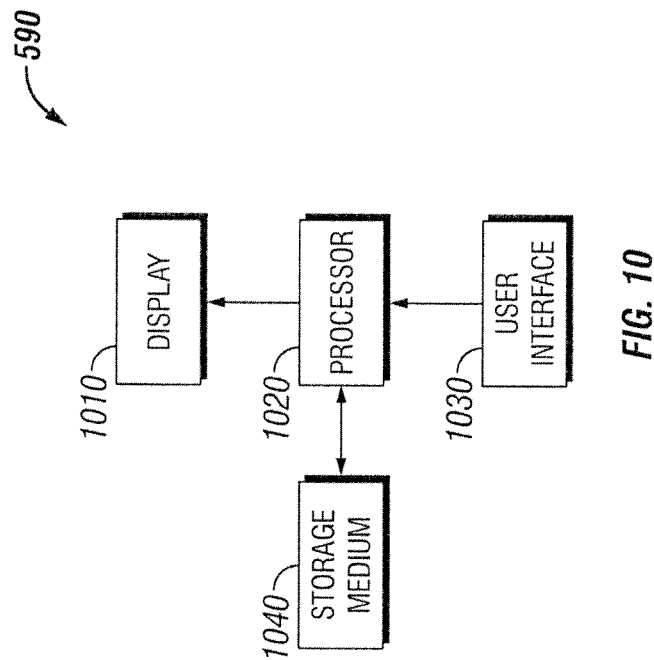


FIG. 10



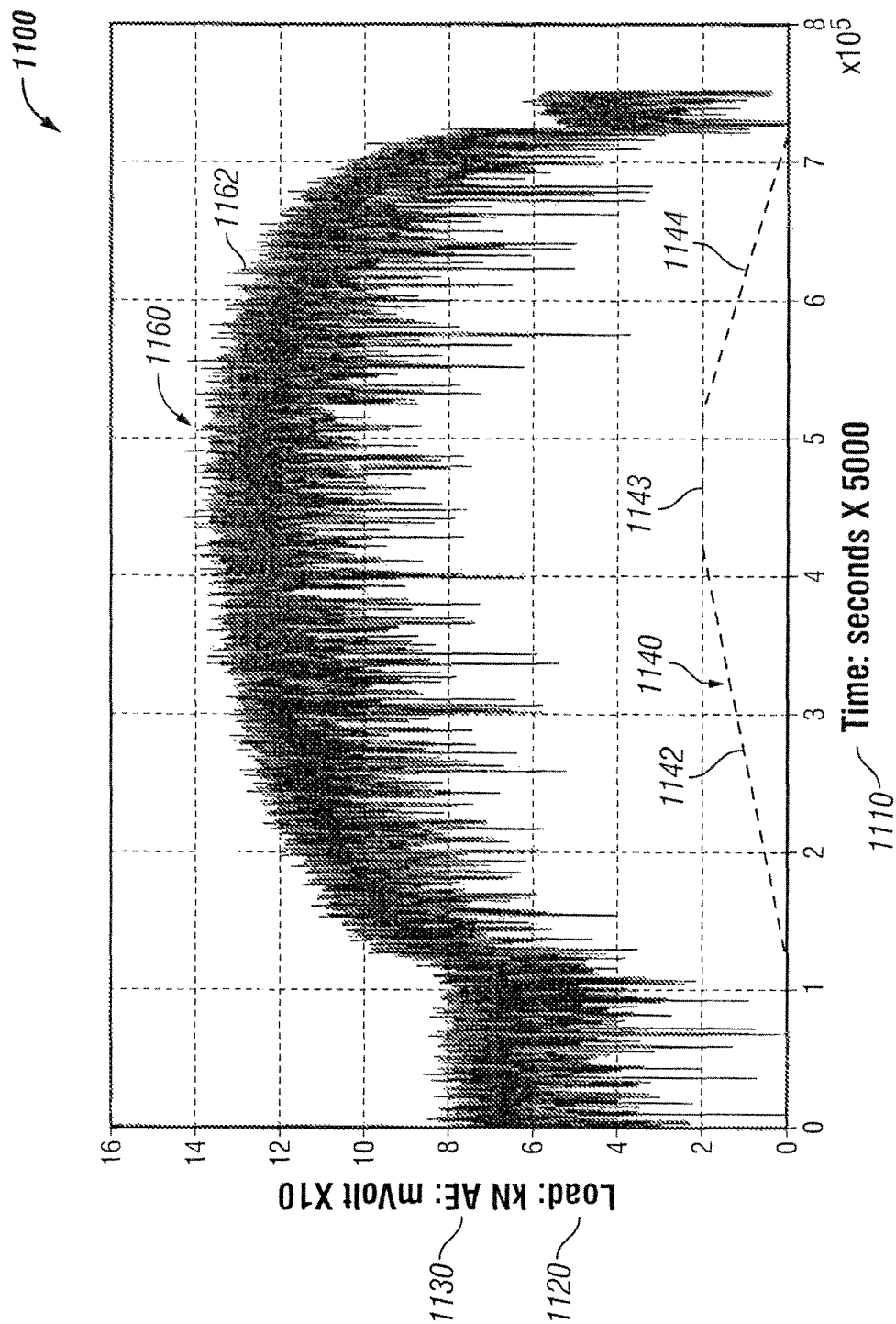


FIG. 11

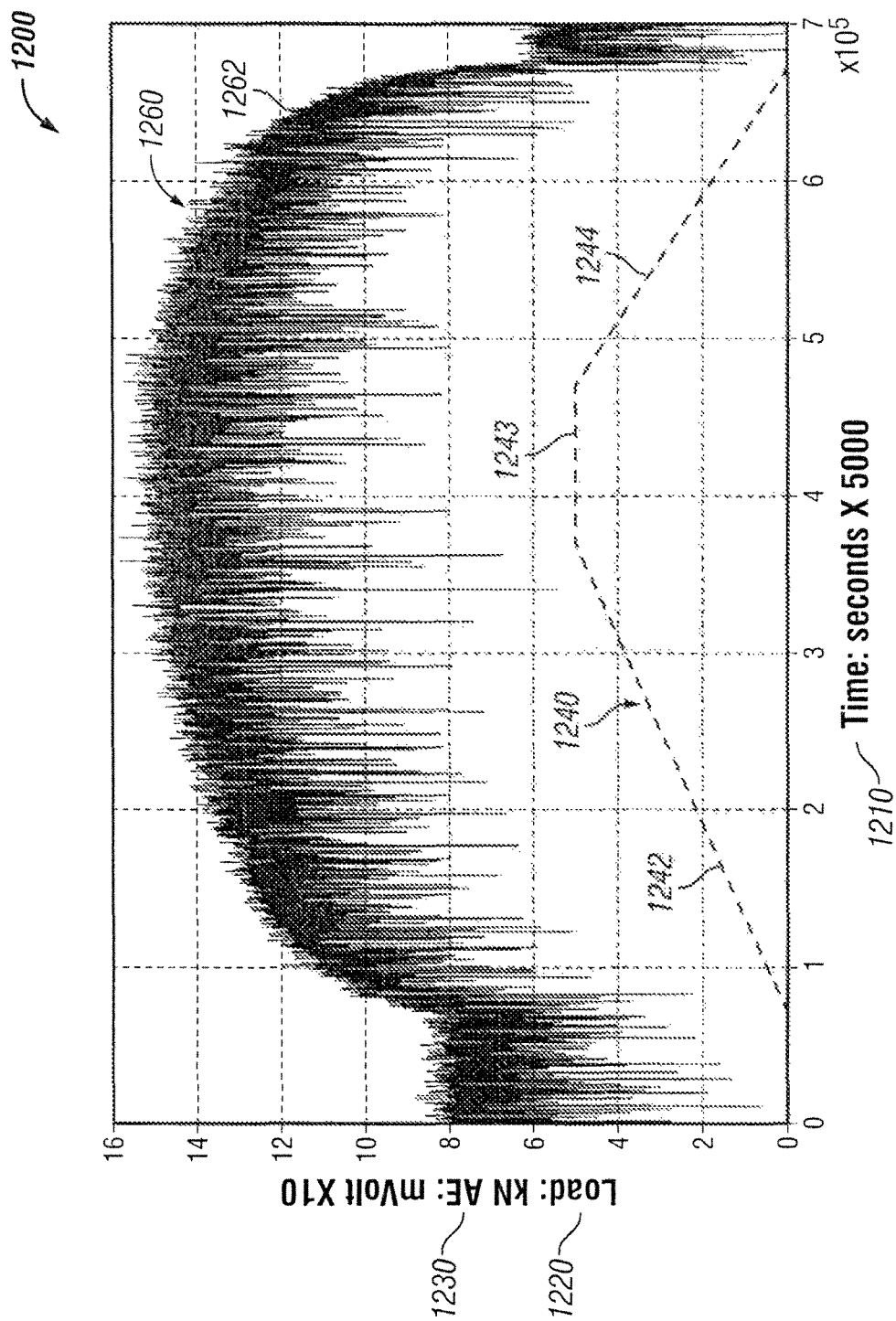


FIG. 12

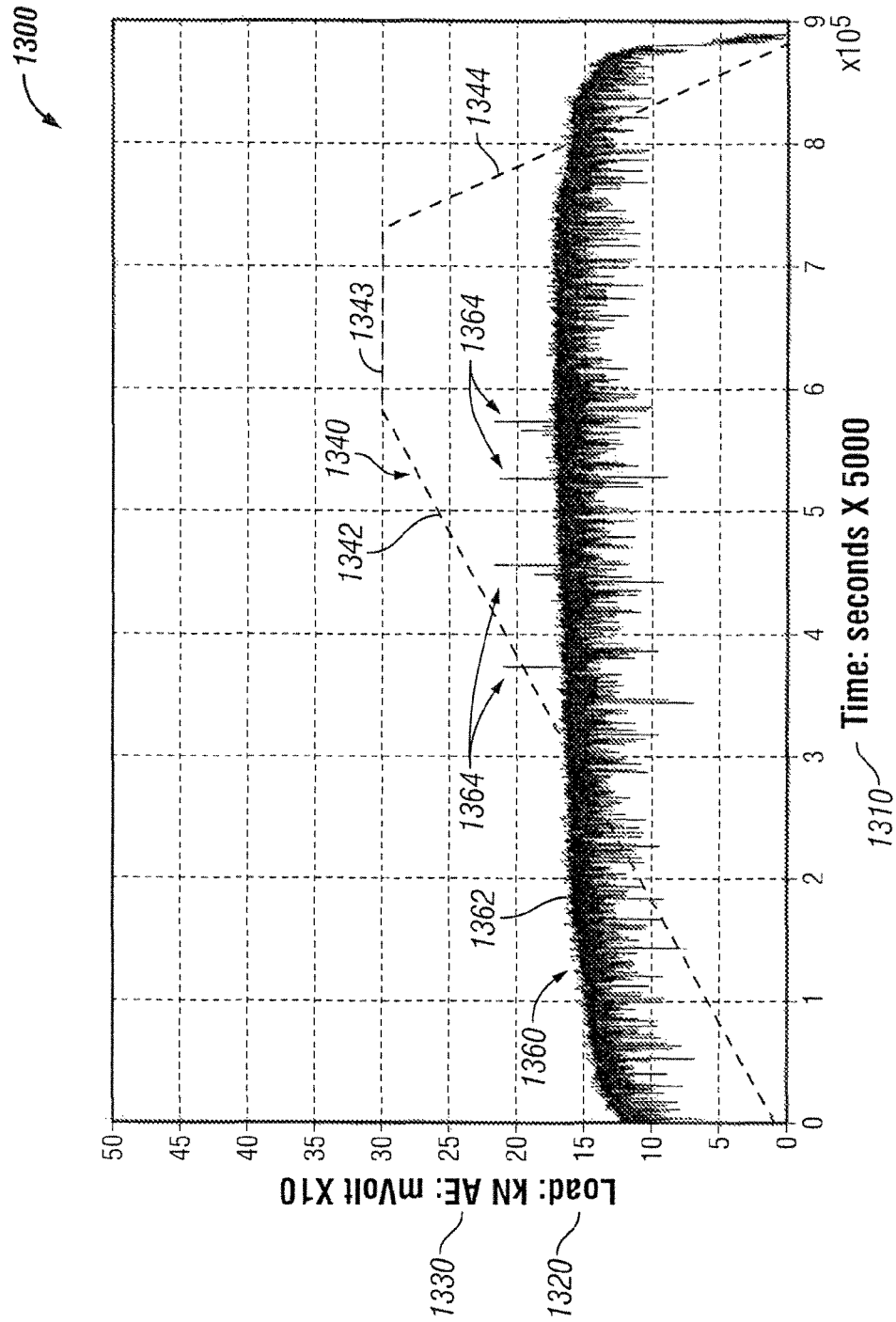


FIG. 13

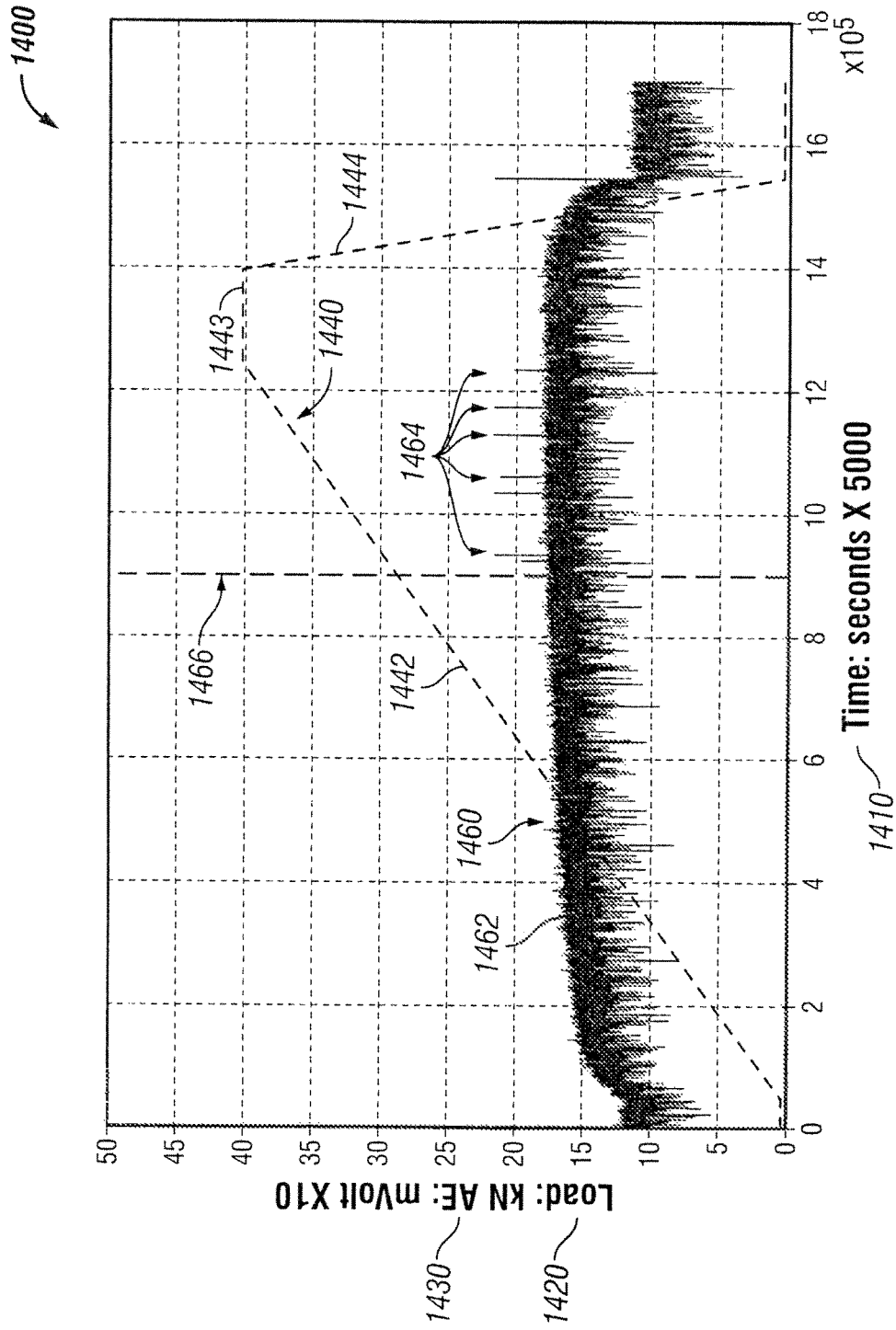
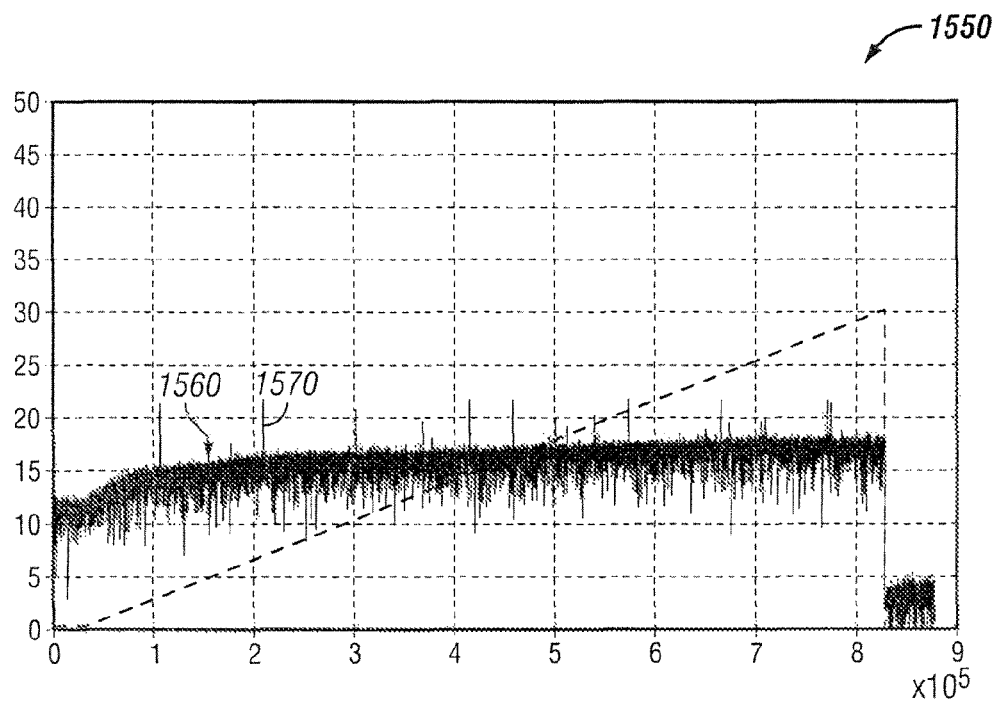
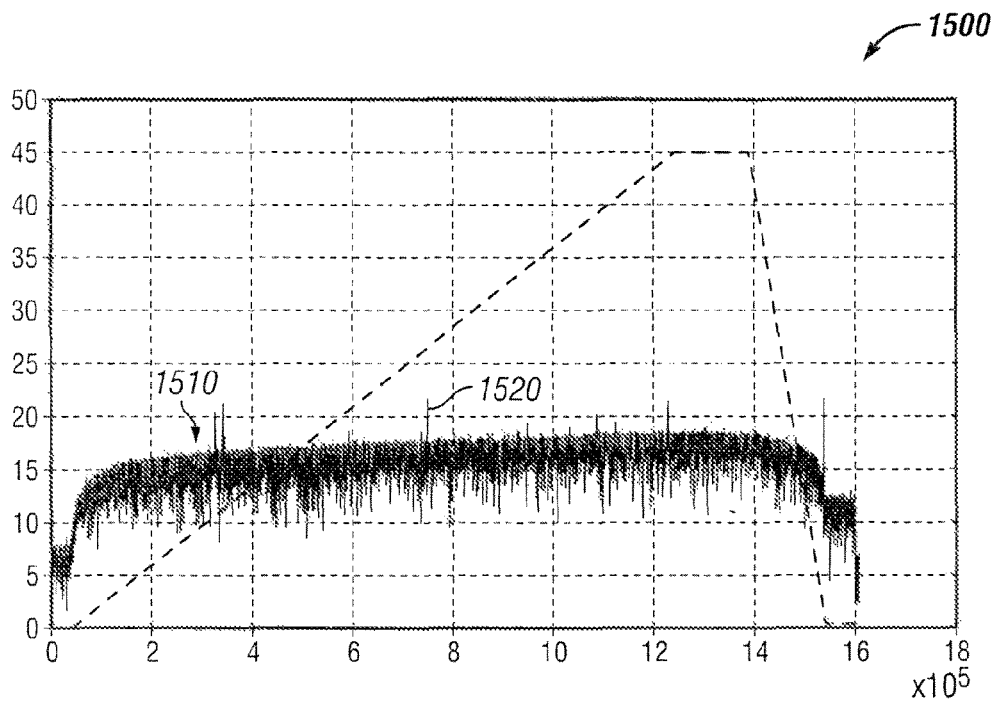


FIG. 14



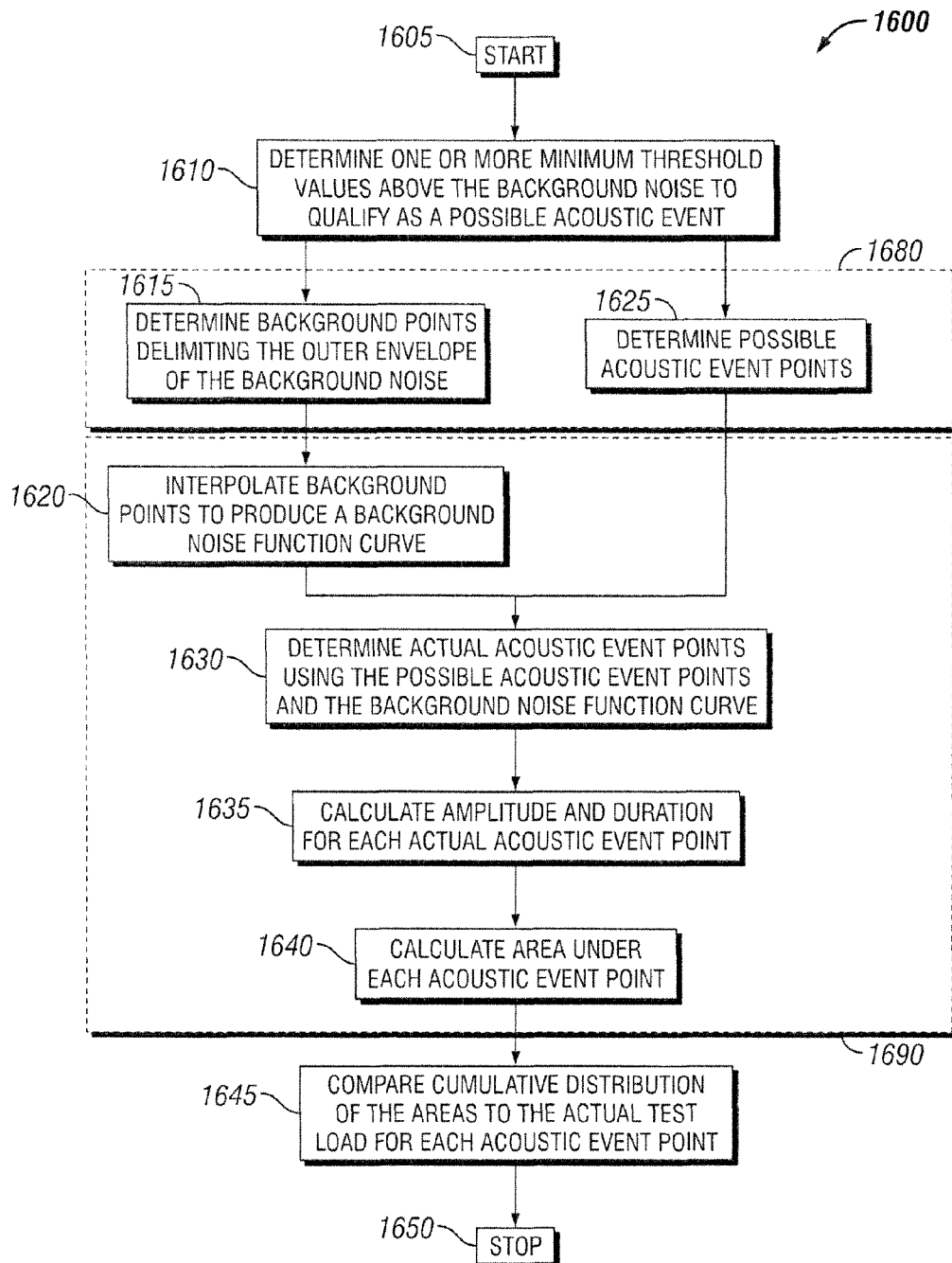


FIG. 16

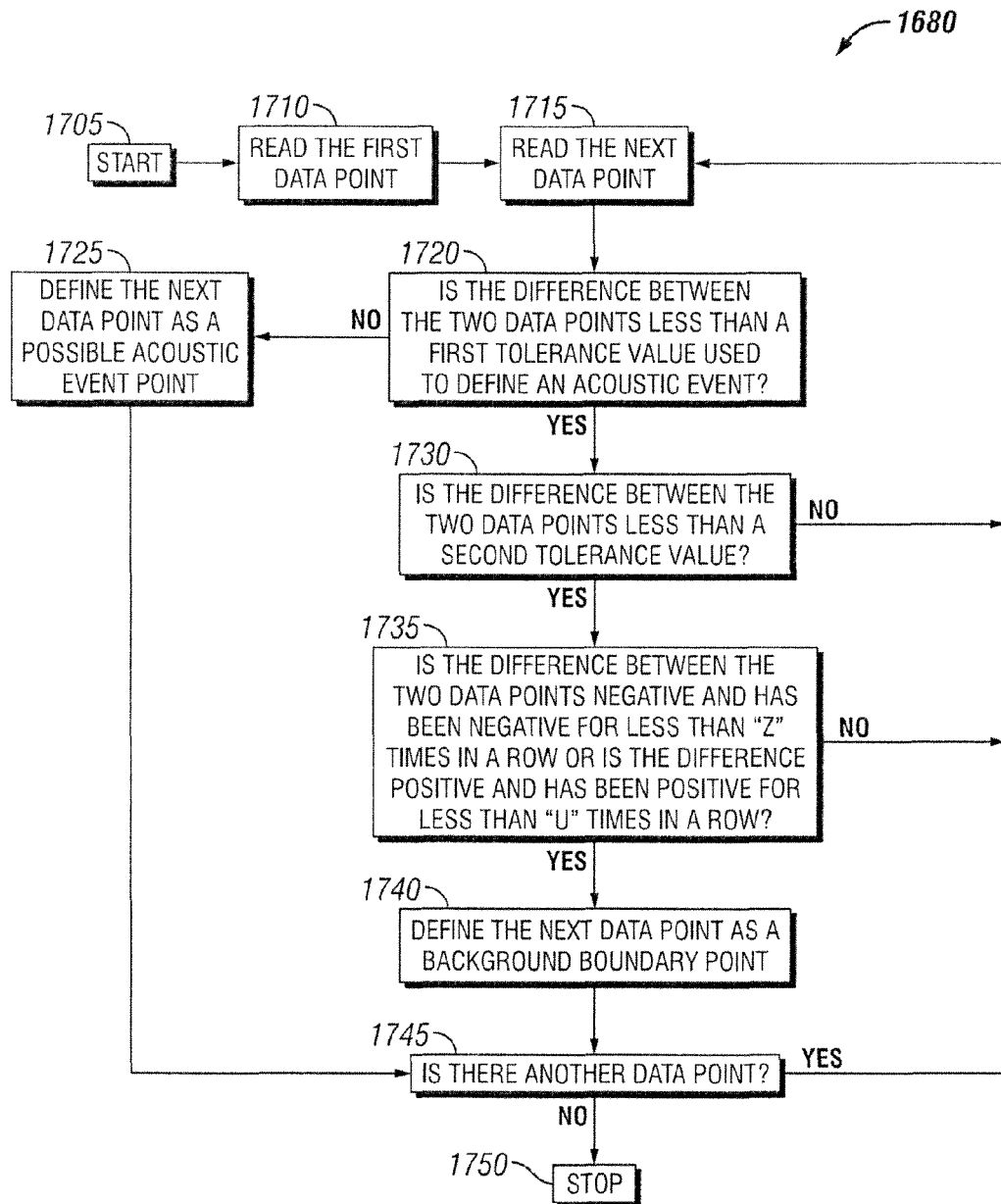


FIG. 17

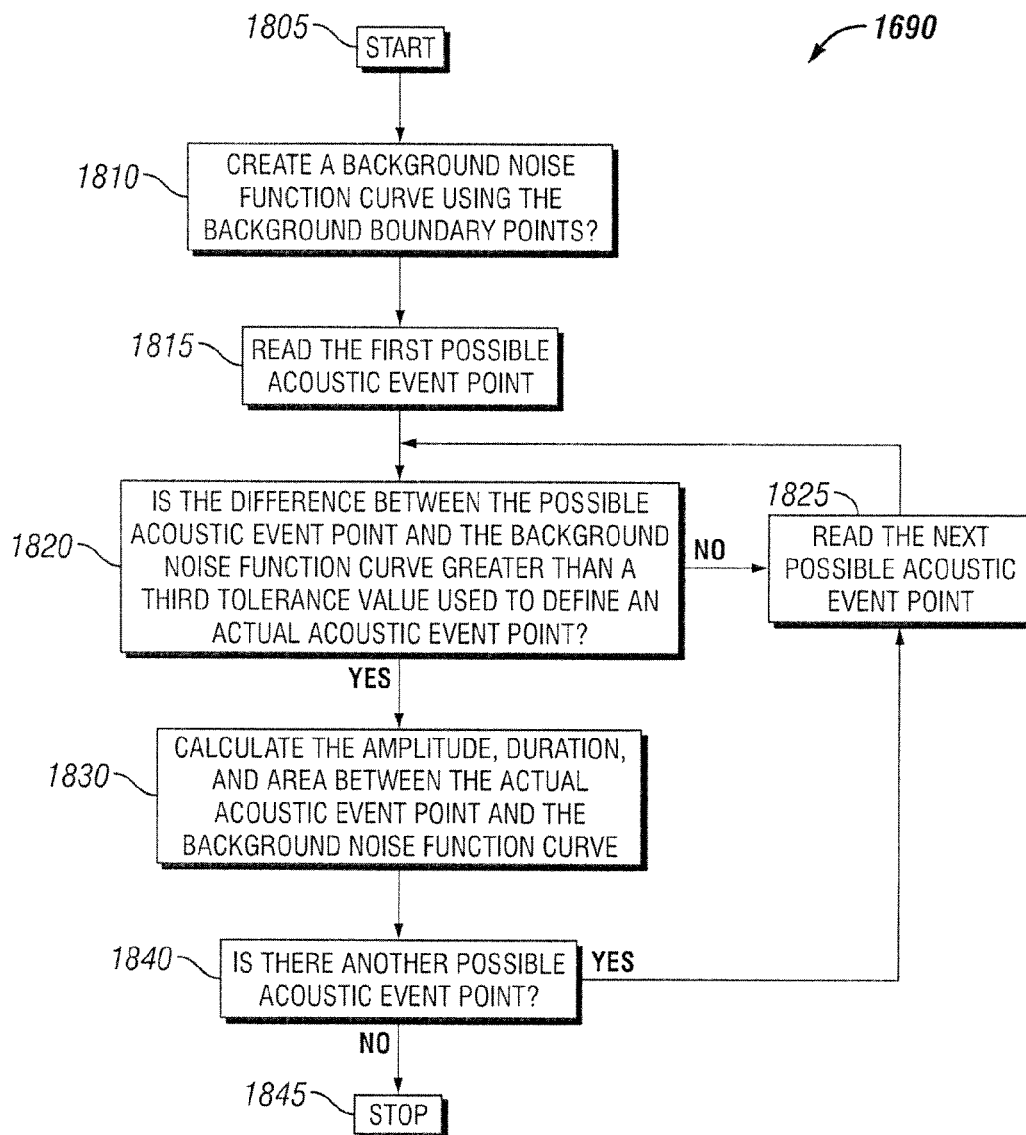


FIG. 18



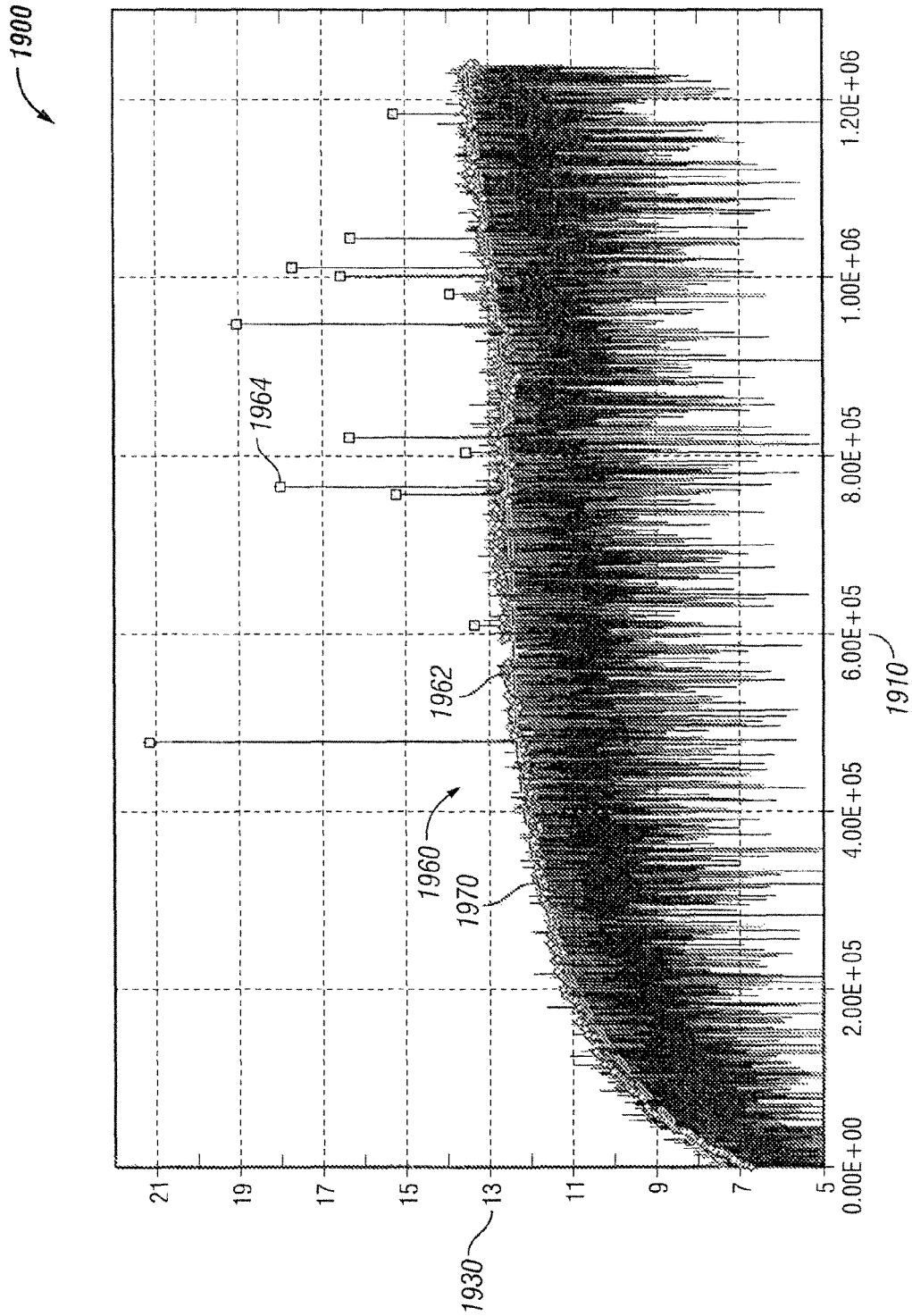


FIG. 19

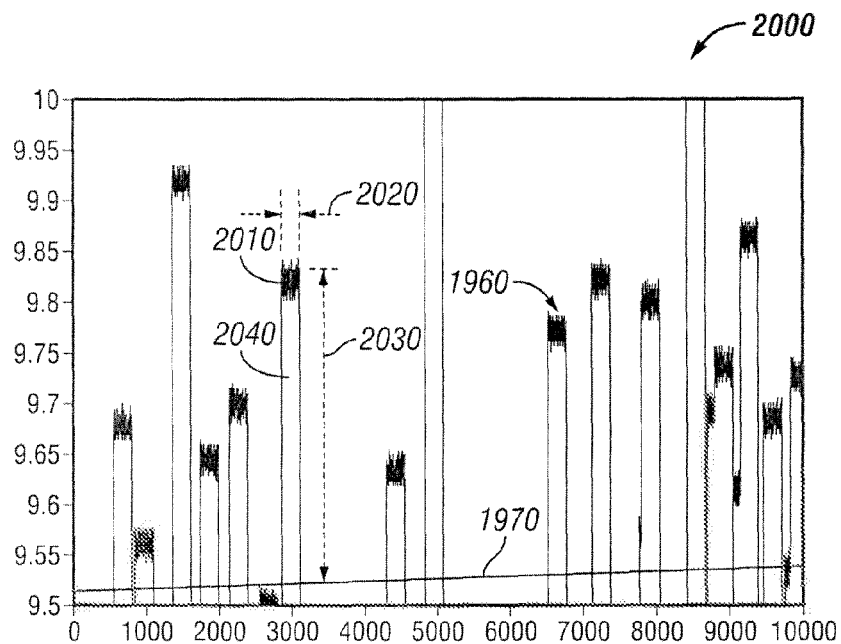


FIG. 20

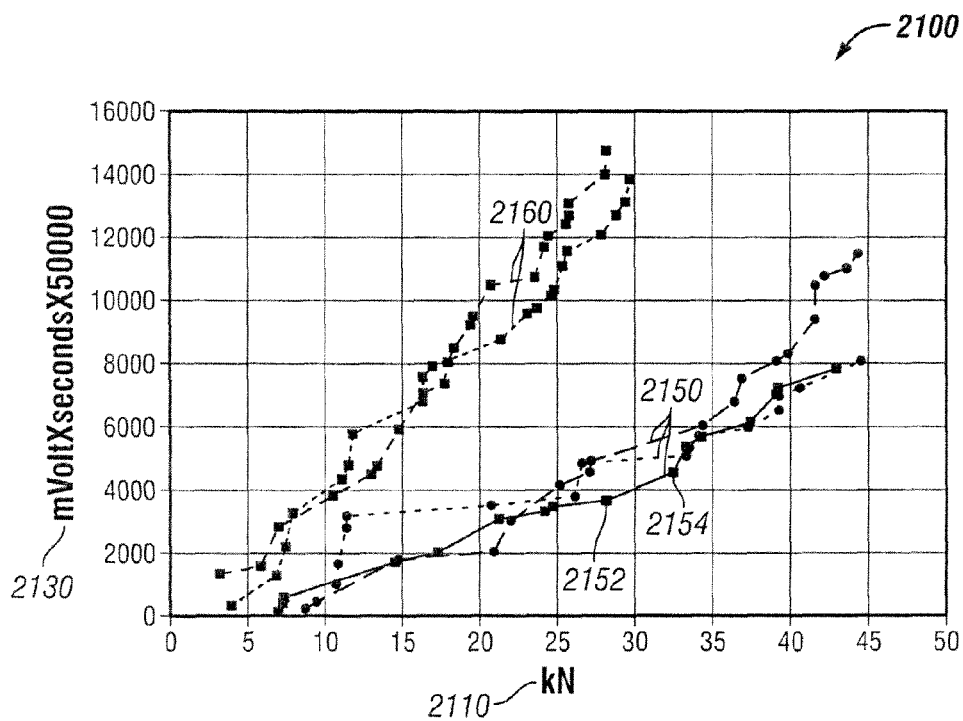


FIG. 21

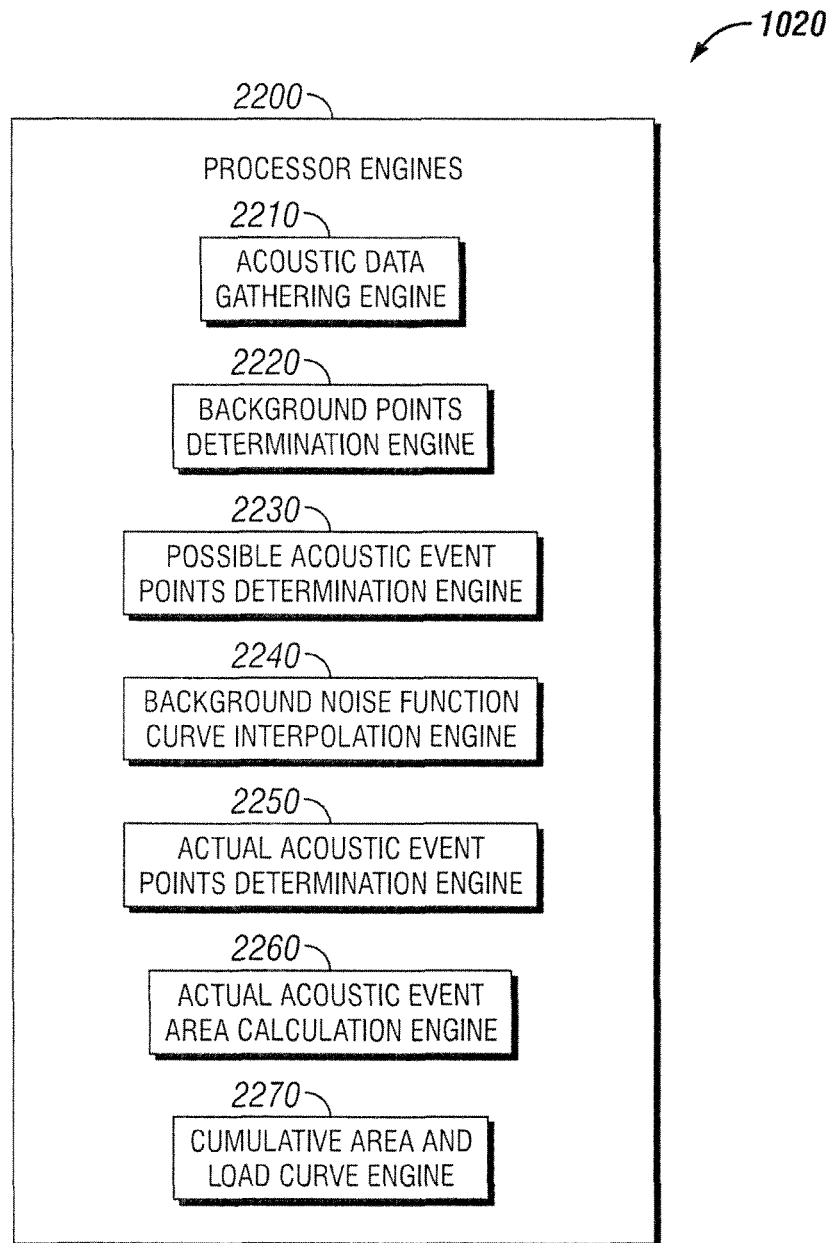
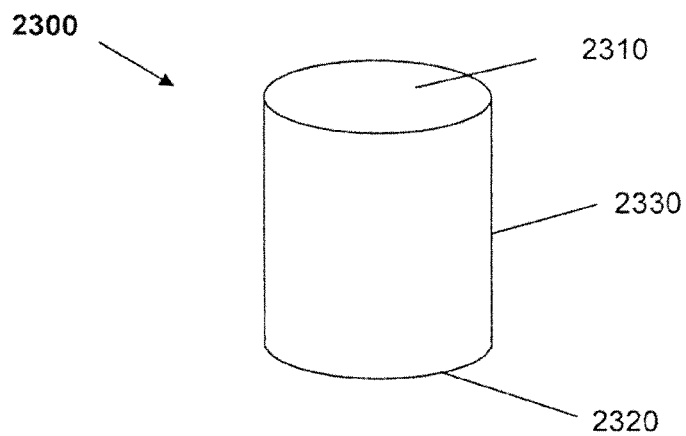
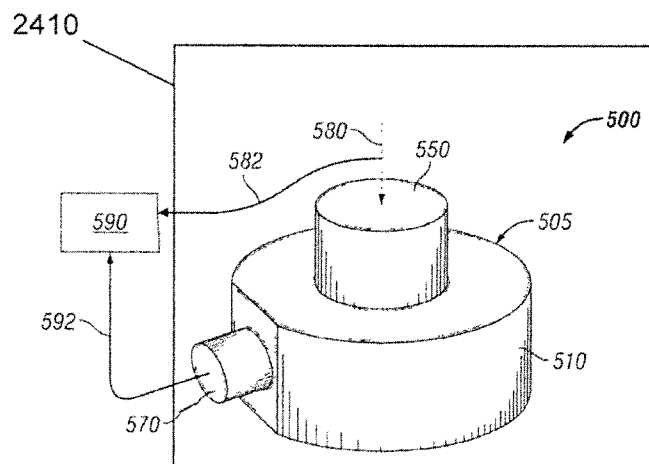


FIG. 22



**FIG. 23**



**FIG. 24**

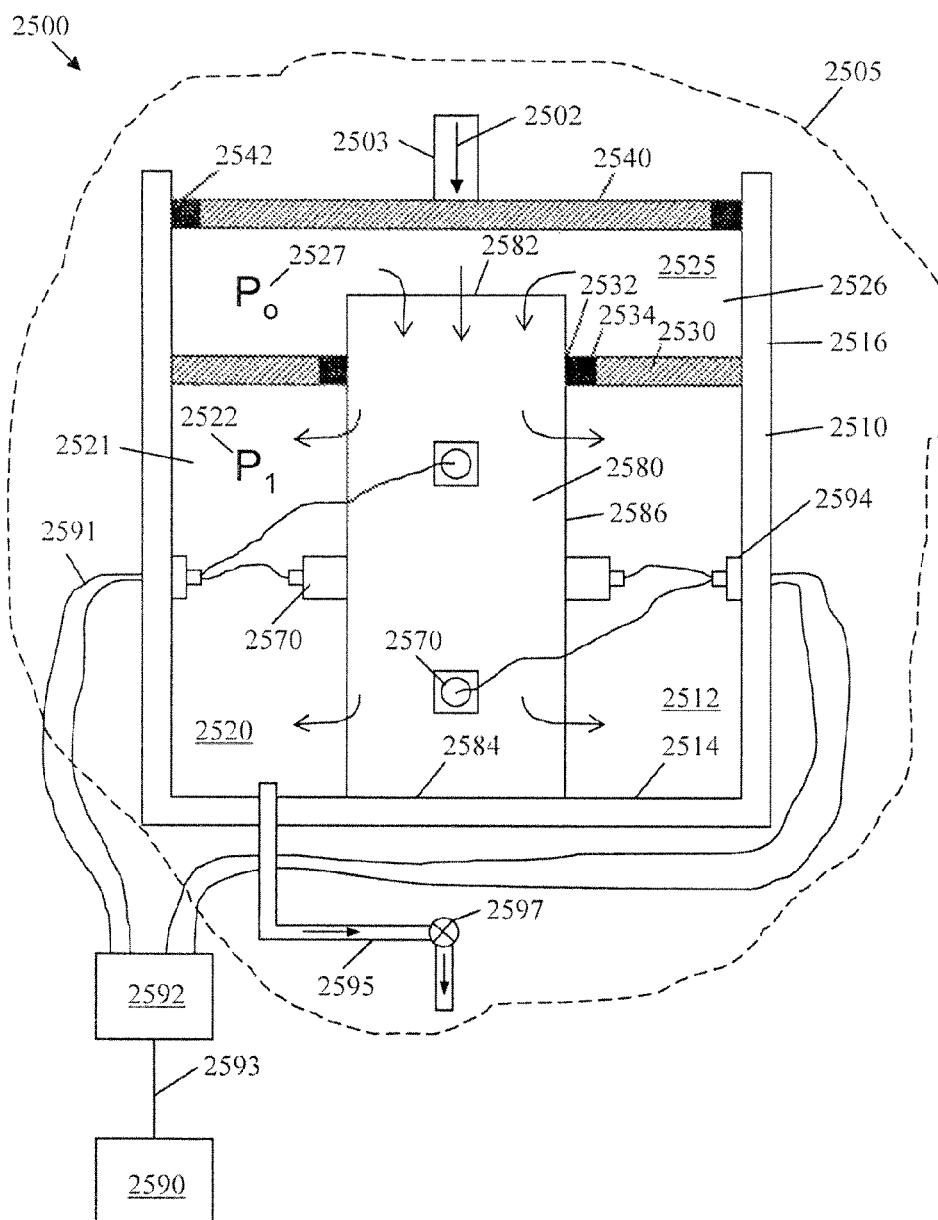


Fig. 25

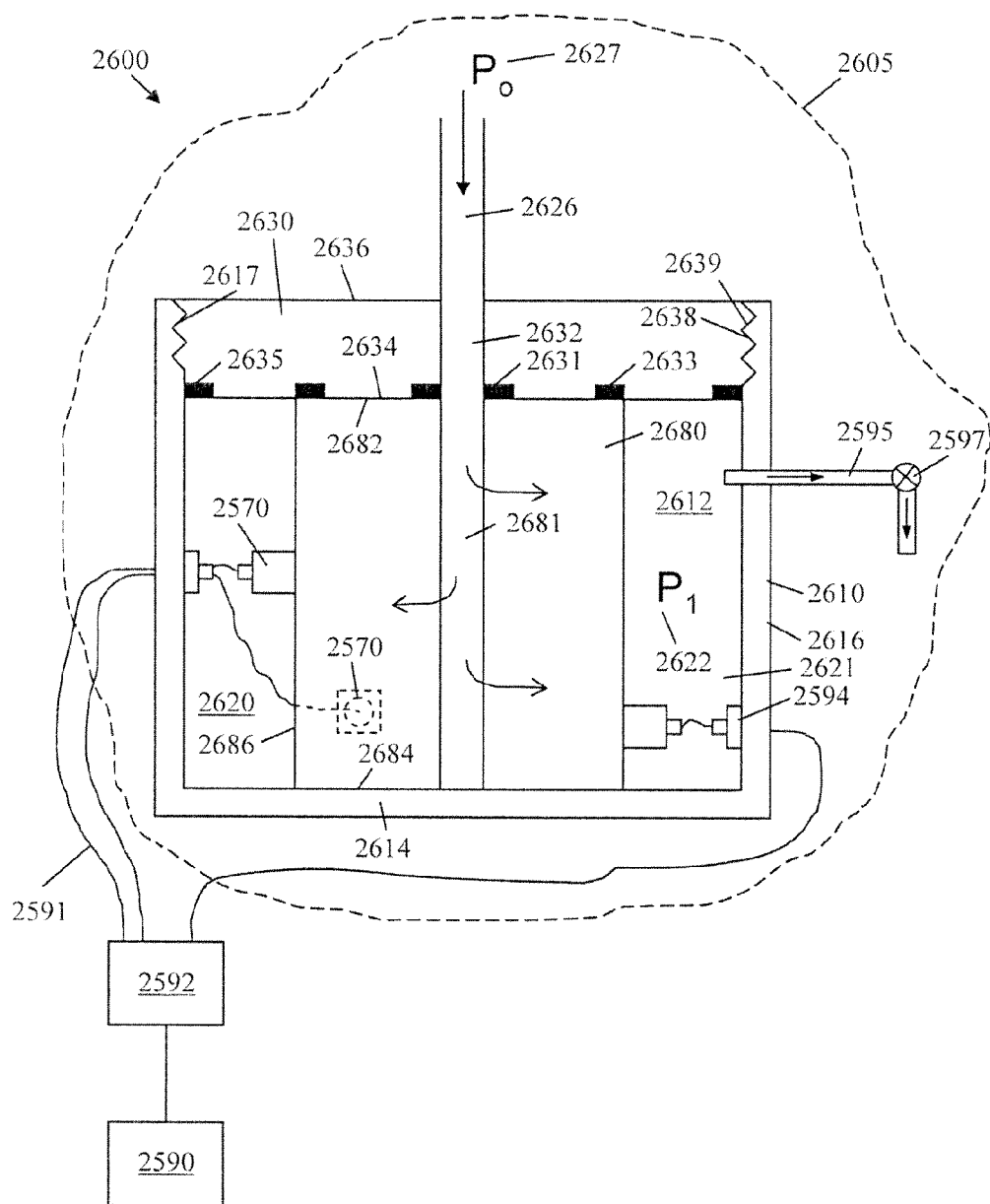
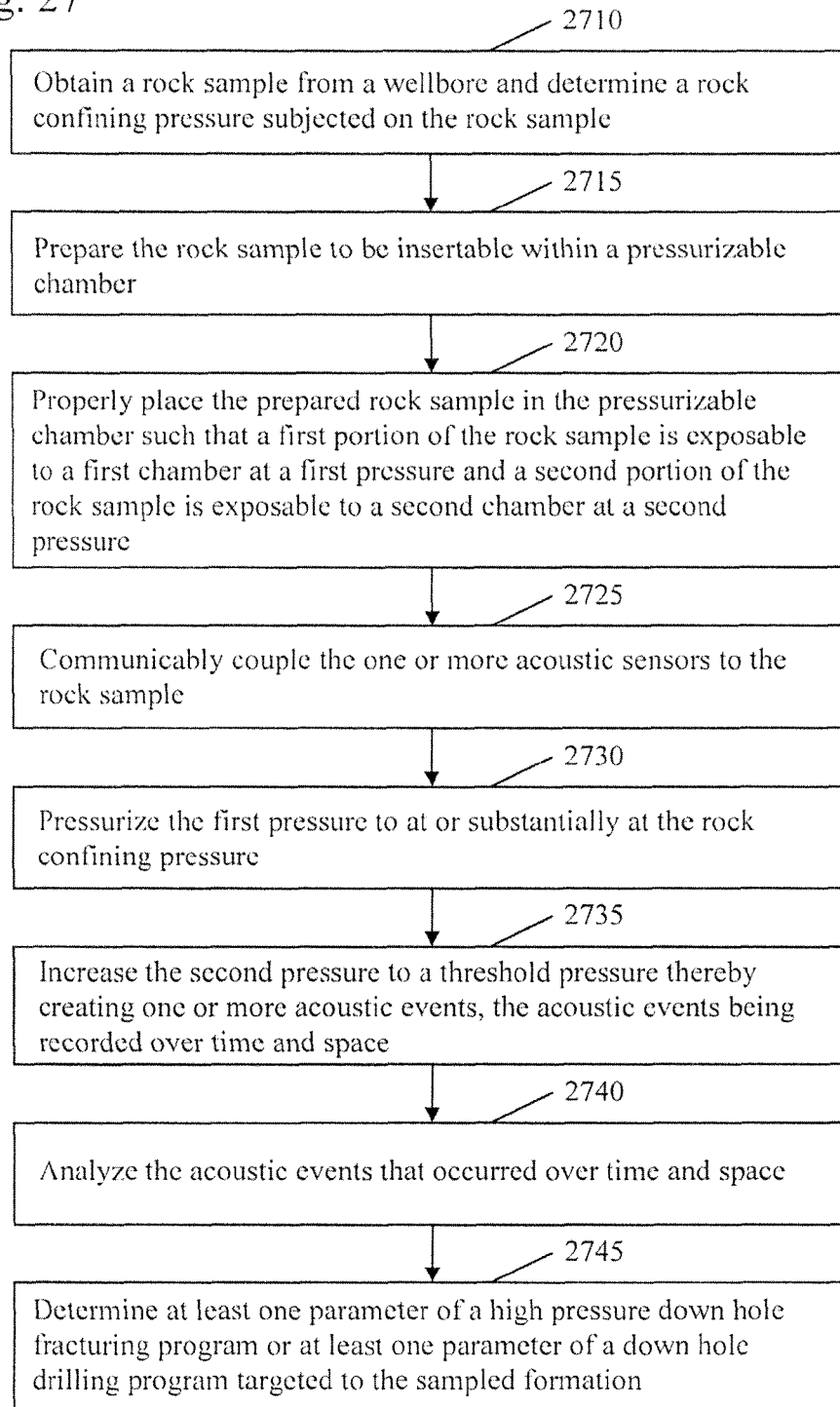


Fig. 26

Fig. 27



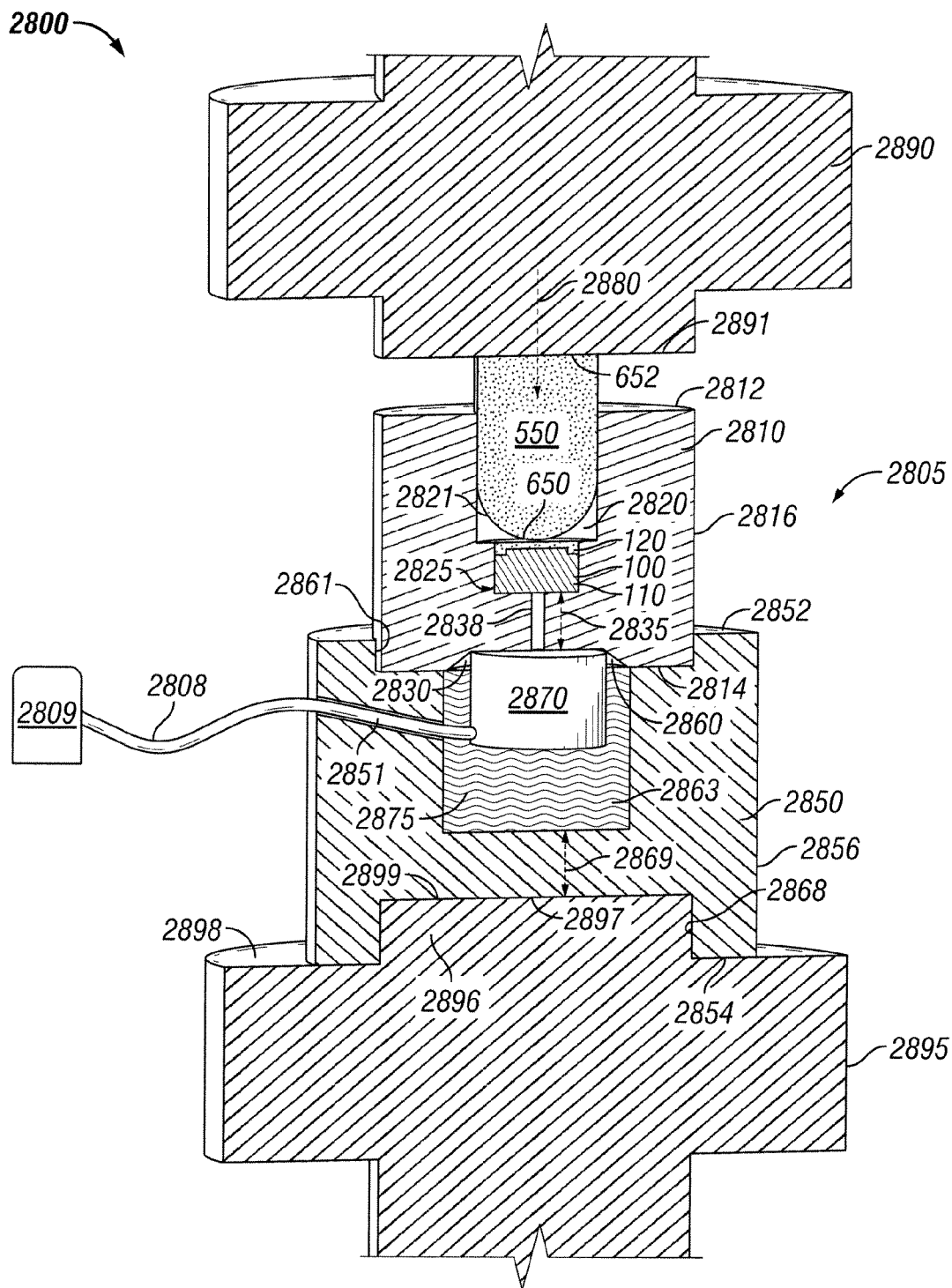


FIG. 28



Figure 29

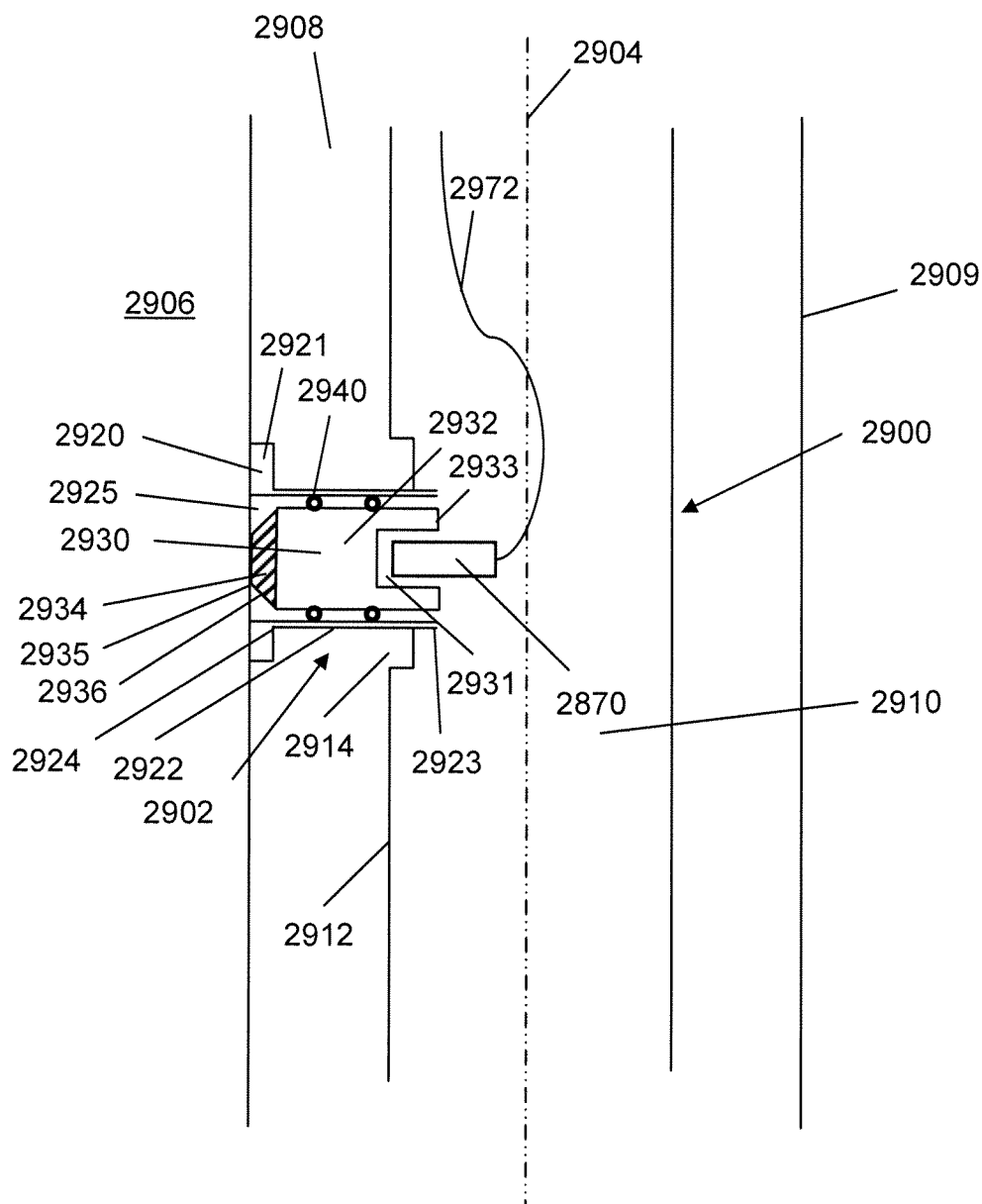


Figure 30

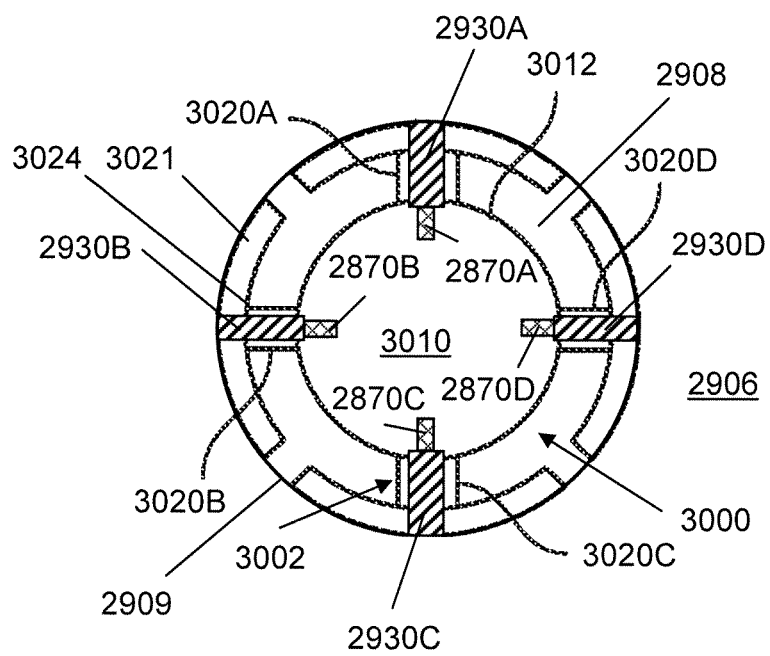


Figure 31

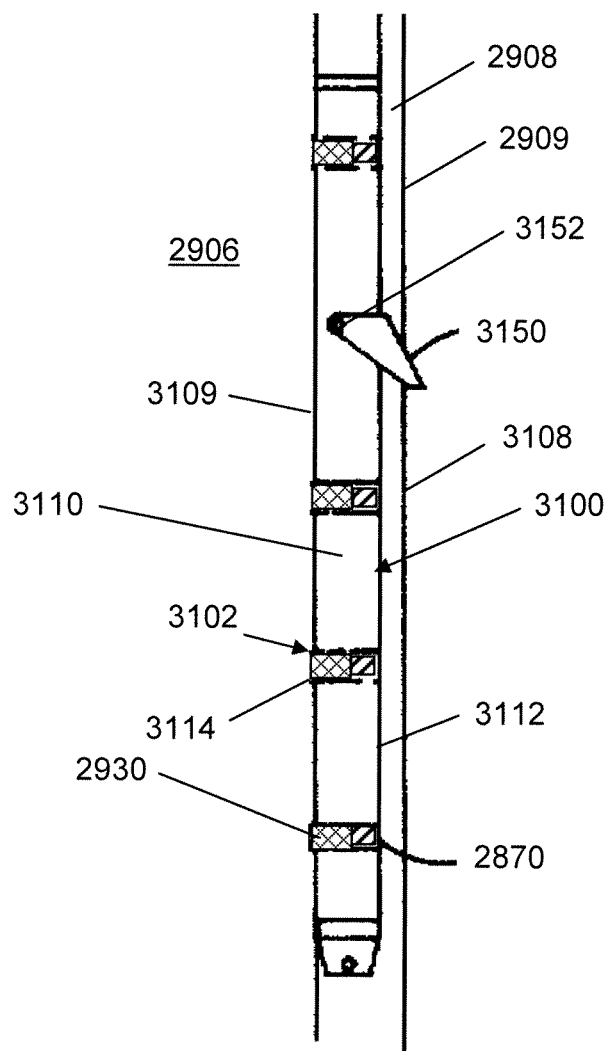
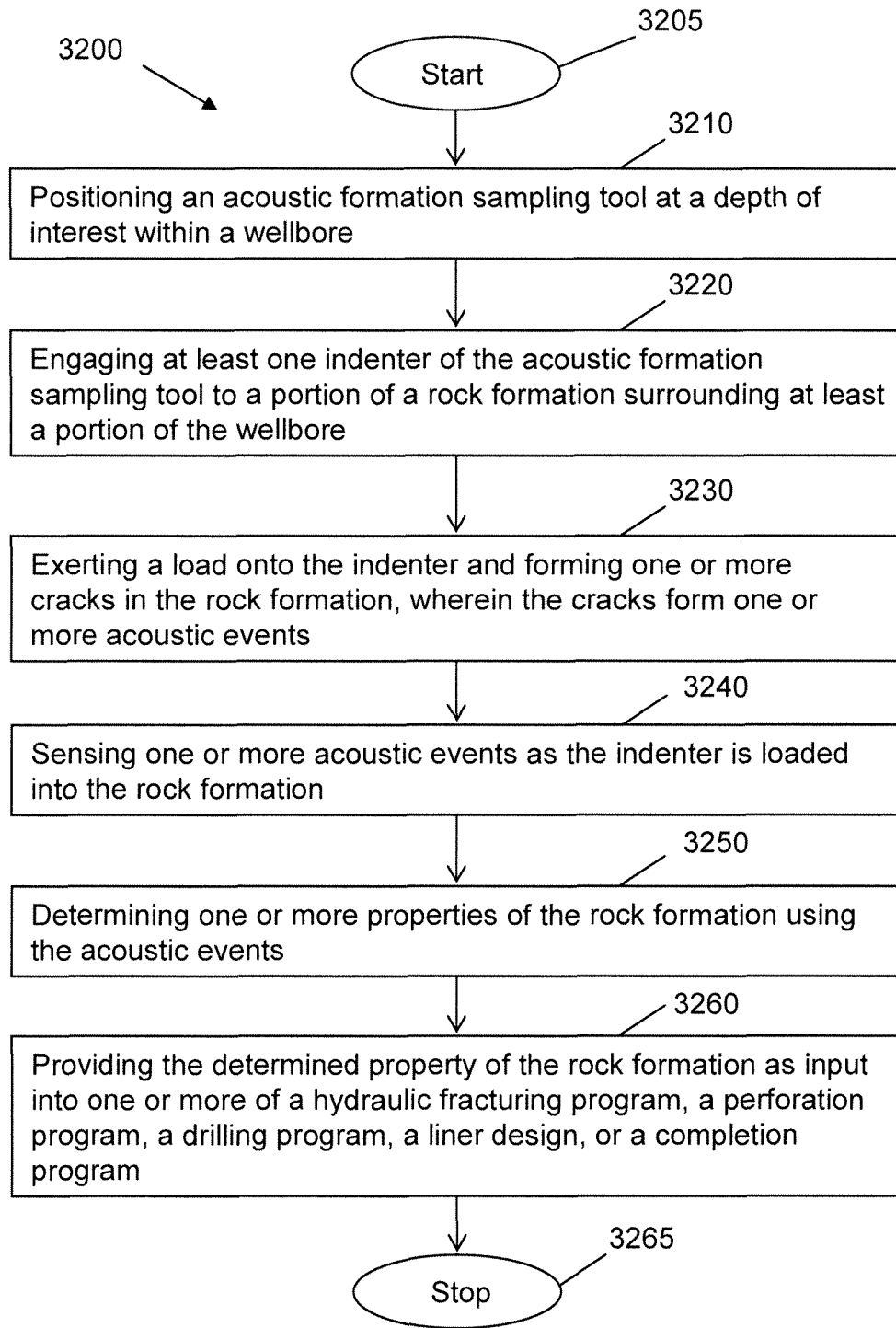


Figure 32



# DOWNHOLE ACOUSTIC EMISSION FORMATION SAMPLING

## RELATED APPLICATIONS

The present application is a continuation-in-part of U.S. patent application Ser. No. 13/152,126, entitled "Acoustic Emission Toughness Testing Having Smaller Noise Ratio" and filed on Jun. 2, 2011, which is a continuation-in-part of U.S. patent application Ser. No. 12/963,913, entitled "Acoustic Emission Toughness Testing For PDC, PCBN, Or Other Hard Or Superhard Materials" and filed on Dec. 9, 2010, which is a continuation-in-part of U.S. patent application Ser. No. 12/769,221, entitled "Acoustic Emission Toughness Testing For PDC, PCBN, Or Other Hard Or Superhard Materials" and filed on Apr. 28, 2010, which is a continuation-in-part of U.S. patent application Ser. No. 12/754,784, entitled "Acoustic Emission Toughness Testing For PDC, PCBN, Or Other Hard Or Superhard Material Inserts" and filed on Apr. 6, 2010, which are all hereby incorporated by reference.

The present application also is related to U.S. patent application Ser. No. 12/754,738, entitled "Acoustic Emission Toughness Testing For PDC, PCBN, Or Other Hard Or Superhard Material Inserts" and filed on Apr. 6, 2010, which also is hereby incorporated by reference.

## TECHNICAL FIELD

The present invention relates generally to a method and apparatus for testing one or more rock properties; and more particularly, to a method and apparatus for testing, in situ, one or more properties, such as compressive strength, of rock formations found within a wellbore using acoustic emissions.

## BACKGROUND

FIG. 1 shows a superhard material **100** that is insertable within a downhole tool (not shown), such as a drill bit or a reamer, in accordance with an exemplary embodiment of the invention. One example of a superhard material **100** is a cutting element **100**, or cutter or insert, for rock bits, as shown in FIG. 1. However, the superhard material **100** can be formed into other structures based upon the application that it is to be used in. In other examples, the superhard material **100** is a rock sample, which can be obtained from within a wellbore or from other sources. The cutting element **100** typically includes a substrate **110** having a contact face **115** and a cutting table **120**. The cutting table **120** is fabricated using an ultra hard layer which is bonded to the contact face **115** by a sintering process according to one example. According to some examples, the substrate **110** is generally made from tungsten carbide-cobalt, or tungsten carbide, while the cutting table **120** is formed using a polycrystalline ultra hard material layer, such as polycrystalline diamond ("PCD") or polycrystalline cubic boron nitride ("PCBN"). These cutting elements **100** are fabricated according to processes and materials known to persons having ordinary skill in the art. Although the cutting table **120** is shown having a substantially planar outer surface, the cutting table **120** can have alternative shaped outer surfaces, such as dome-shaped, concave-shaped, or other non-planar shaped outer surfaces, in other embodiments. Although some exemplary formulations for the cutting element **100** have been provided, other formulations and structures known to people having ordinary skill in the art can be used depending upon the application. Although rock drilling is one application that the superhard material **100** can be used in or obtained from and which is

described hereinbelow, the superhard material **100** can be used in or obtained from various other applications including, but not limited to, machining, woodworking, and quarrying.

Different PCD, PCBN, hard, and superhard material grades are available for the cutters **100** to be used in various applications, such as drilling different rock formations using different drill bit designs or machining different metals or materials. Common problems associated with these cutters **100** include chipping, spalling, partial fracturing, cracking, and/or flaking of the cutting table **120** during use. These problems result in the early failure of the cutting table **120** and/or the substrate **110**. Typically, high magnitude stresses generated on the cutting table **120** at the region where the cutting table **120** makes contact with earthen formations during drilling can cause these problems. These problems increase the cost of drilling due to costs associated with repair, production downtime, and labor costs. Thus, an end-user, such as a bit designer or a field application engineer, chooses the best performing grade of the cutter **100** for any given drilling or machining task to reduce these common problems from occurring. For example, the end-user selects an appropriate cutter **100** by balancing the wear resistance and the impact resistance of the cutter **100**, as determined using conventional methods. Typically, the information available to the end-user for selecting the appropriate grade cutter **100** for a particular application is derived from historical data records that show performance of different grades of PCD, PCBN, hard, or superhard material in specific areas and/or from laboratory functional tests which attempt to mimic various drilling or machining conditions while testing different cutters **100**. There are currently two main categories of laboratory functional testing that are used in the drilling industry. These tests are the wear abrasion test and the impact test.

Superhard materials **100**, which include polycrystalline diamond compact ("PDC") cutters **100**, have been tested for abrasive wear resistance through the use of two conventional testing methods. The PDC cutter **100** includes the cutting table **120** fabricated from PCD. FIG. 2 shows a lathe **200** for testing abrasive wear resistance using a conventional granite log test. Although one exemplary apparatus configuration for the lathe **200** is provided, other apparatus configurations known to people having ordinary skill in the art can be used without departing from the scope and spirit of the exemplary embodiment.

Referring to FIG. 2, the lathe **200** includes a chuck **210**, a tailstock **220**, and a tool post **230** positioned between the chuck **210** and the tailstock **220**. A target cylinder **250** has a first end **252**, a second end **254**, and a sidewall **258** extending from the first end **252** to the second end **254**. According to the conventional granite log test, sidewall **258** is an exposed surface **259** which makes contact with the superhard component **100** during the test. The first end **252** is coupled to the chuck **210**, while the second end **254** is coupled to the tailstock **220**. The chuck **210** is configured to rotate, thereby causing the target cylinder **250** to also rotate along a central axis **256** of the target cylinder **250**. The tailstock **220** is configured to hold the second end **254** in place while the target cylinder **250** rotates. The target cylinder **250** is fabricated from a single uniform material, which is typically granite. However, other rock types have been used for the target cylinder **250**, which includes, but is not limited to, Jackfork sandstone, Indiana limestone, Berea sandstone, Carthage marble, Champlain black marble, Berkley granite, Sierra white granite, Texas pink granite, and Georgia gray granite.

The PDC cutter **100** is fitted to the lathe's tool post **230** so that the PDC cutter **100** makes contact with the target cylinder's **250** exposed surface **259**. The lathe's tool post **230**

draws the PDC cutter **100** back and forth across the exposed surface **259**. The tool post **230** has an inward feed rate on the target cylinder **250**. The abrasive wear resistance for the PDC cutter **100** is determined as a wear ratio, which is defined as the volume of target cylinder **250** that is removed to the volume of the PDC cutter **100** that is removed. Alternatively, instead of measuring volume, the distance that the PDC cutter **100** travels across the target cylinder **250** can be measured and used to quantify the abrasive wear resistance for the PDC cutter **100**. Alternatively, other methods known to persons having ordinary skill in the art can be used to determine the wear resistance using the granite log test. Operation and construction of the lathe **200** is known to people having ordinary skill in the art. Descriptions of this type of test is found in the Eaton, B. A., Bower, Jr., A. B., and Martis, J. A. "Manufactured Diamond Cutters Used In Drilling Bits." *Journal of Petroleum Technology*, May 1975, 543-551. Society of Petroleum Engineers paper 5074-PA, which was published in the *Journal of Petroleum Technology* in May 1975, and also found in Maurer, William C., *Advanced Drilling Techniques*, Chapter 22, The Petroleum Publishing Company, 1980, pp. 541-591, which is incorporated by reference herein.

FIG. 3 shows a vertical boring mill **300** for testing abrasive wear resistance using a vertical boring mill ("VBM") test or vertical turret lathe ("VTL") test. Although one exemplary apparatus configuration for the VBM **300** is provided, other apparatus configurations can be used without departing from the scope and spirit of the exemplary embodiment. The vertical boring mill **300** includes a rotating table **310** and a tool holder **320** positioned above the rotating table **310**. A target cylinder **350** has a first end **352**, a second end **354**, and a sidewall **358** extending from the first end **352** to the second end **354**. According to the conventional VBM test, second end **354** is an exposed surface **359** which makes contact with a superhard material **100** during the test. The target cylinder **350** is typically about thirty inches to about sixty inches in diameter; however, this diameter can be greater or smaller.

The first end **352** is mounted on the lower rotating table **310** of the VBM **300**, thereby having the exposed surface **359** face the tool holder **320**. The PDC cutter **100** is mounted in the tool holder **320** above the target cylinder's exposed surface **359** and makes contact with the exposed surface **359**. The target cylinder **350** is rotated as the tool holder **320** cycles the PDC cutter **100** from about the center of the target cylinder's exposed surface **359** out to about its edge and back again to about the center of the target cylinder's exposed surface **359**. The tool holder **320** has a predetermined downward feed rate. The VBM method allows for higher loads to be placed on the PDC cutter **100** and the larger target cylinder **350** provides for a greater rock volume for the PDC cutter **100** to act on. The target cylinder **350** is typically fabricated from granite; however, the target cylinder can be fabricated from other materials that include, but is not limited to, Jackfork sandstone, Indiana limestone, Berea sandstone, Carthage marble, Champlain black marble, Berkley granite, Sierra white granite, Texas pink granite, and Georgia gray granite.

The abrasive wear resistance for the PDC cutter **100** is determined as a wear ratio, which is defined as the volume of target cylinder **350** that is removed to the volume of the PDC cutter **100** that is removed. Alternatively, instead of measuring volume, the distance that the PDC cutter **100** travels across the target cylinder **350** can be measured and used to quantify the abrasive wear resistance for the PDC cutter **100**. Alternatively, other methods known to persons having ordinary skill in the art can be used to determine the wear resistance using the VBM test. Operation and construction of the VBM **300** is known to people having ordinary skill in the art.

A description for this type of testing can be found in Bertagnolli, Ken and Vale, Roger, "Understanding and Controlling Residual Stresses in Thick Polycrystalline Diamond Cutters for Enhanced Durability," US Synthetic Corporation, 2000, which is incorporated by reference in its entirety herein.

In addition to testing for abrasive wear resistance, PDC cutters **100** also can be tested for resistance to impact loading. FIG. 4 shows a drop tower apparatus **400** for testing impact resistance of superhard components using a "drop hammer" test where a metal weight **450** is suspended above and dropped onto the cutter **100**. The "drop hammer" test attempts to emulate the type of loading that can be encountered when the PDC cutter **100** transitions from one formation to another or experiences lateral and axial vibrations. Results from the impact testing allows for ranking different cutters based upon their impact strength; however, these ranking do not allow for predictions to be made according to how the cutters **100** will perform in the actual field.

Referring to FIG. 4, the drop tower apparatus **400** includes a superhard material **100**, such as a PDC cutter, a target fixture **420**, and a strike plate **450** positioned above the superhard material **100**. The PDC cutter **100** is locked into the target fixture **420**. The strike plate **450**, or weight, is typically fabricated from steel and is positioned above the PDC cutter **100**. However, the strike plate **450** can be fabricated from alternative materials known to persons having ordinary skill in the art. The PDC cutter **100** is typically held at a backrake angle **415** with the diamond table **120** of the PDC cutter **100** angled upward towards the strike plate **450**. The range for the backrake angle **415** is known to people having ordinary skill in the art.

The strike plate **450** is repeatedly dropped down on the edge of the PDC cutter **100** until the edge of the PDC cutter **100** breaks away or spalls off. These tests are also referred to as "side impact" tests because the strike plate **450** impacts an exposed edge of the diamond table **120**. Failures typically appear in either the diamond table **120** or at the contact face **115** between the diamond table **120** and the carbide substrate **110**. The "drop hammer" test is very sensitive to the edge geometry of the diamond table **120**. If the table **120** is slightly chamfered, the test results can be altered considerably. The total energy, expressed in Joules, expended to make the initial fracture in the diamond table **120** is recorded. For more highly impact resistant cutters **100**, the strike plate **450** can be dropped according to a preset plan from increasing heights to impart greater impact energy on the cutter **100** to achieve failure. However, this "drop hammer" test embodies drawbacks in that this method requires that many cutters **100** be tested to achieve a valid statistical sampling that can compare the relative impact resistance of one cutter type to another cutter type. The test is inadequate in providing results that reflect the true impact resistance of the entire cutter **100** as it would see impact loads in a downhole environment. The test exhibits a static impact effect whereas the true impact is dynamic. The number of impacts per second can be as high as 100 hertz ("Hz"). Also, the amount of damage to the cutter **100** is subjectively evaluated by someone with a trained eye and is compared to damages incurred by other cutters.

While the results for different wear tests available in the market have generally a reasonable degree of agreement with the actual field performance, the same is not the case for the results of conventional impact tests. Although there is some degree of correlation between the results of conventional impact tests and actual field performance, the scattering of the data is usually very large, thereby causing predictions on how cutters will behave in actual field performance to be difficult and/or inaccurate. Also, many fractures occurring within the

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cutter are not detected using these conventional tests and therefore go undetected when evaluating the toughness of the cutter.

Additionally, since the bit selection is a critical process, it is important to know the mechanical properties of the different rocks, or rock formations, the bit is to drill through. One of the most important parameters currently used for the bit selection is the unconfined compressive strength ("UCS") of the rock, which can be measured directly on core samples obtained from the rock formations within the wellbore or evaluated indirectly from log data. However, the UCS of the rock should not be solely relied on when selecting the bit because the UCS can be misleading, especially when the rock UCS is greater than 15000 psi and is brittle, thereby having a low fracture toughness  $K_{IC}$ . Thus, fracture toughness of the rock should also be considered when selecting the proper drill bit.

In oil well drilling and completion operations, it is beneficial to know the compressive strength of various rock formations within the well plan. These compressive strengths can be used to plan drilling operations since, as previously mentioned, the compressive strength affects the drill bit selection and casing plan among other drilling operations. For completions operations, it is beneficial to know the compressive strength to plan fracturing operations. One method used for determining the compressive strength of a rock formation within the wellbore is to calculate the compressive strength from electric log data, such as sonic logs, electric resistivity, and gamma logs. However, inaccuracies occur when calculating compressive strength from electric log data. Inaccuracies develop because log interpretation requires some calibration with core data. Another method used for determining the compressive strength of a rock formation within the wellbore is to retrieve a core sample, or rock sample, from the rock formation within the wellbore and directly measure the compressive strength. However, inaccuracies also occur when directly measuring the compressive strength from a retrieved core sample. Inaccuracies develop because the calculated compressive strength is performed at the surface and not in the wellbore; and therefore, it is the unconfined compressive strength ("UCS") that is determined rather than the confined compressive strength ("CCS").

#### BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other features and aspects of the invention are best understood with reference to the following description of certain exemplary embodiments, when read in conjunction with the accompanying drawings, wherein:

FIG. 1 shows a superhard material that is insertable within a downhole tool in accordance with an exemplary embodiment of the invention;

FIG. 2 shows a lathe for testing abrasive wear resistance using a conventional granite log test;

FIG. 3 shows a vertical boring mill for testing abrasive wear resistance using a vertical boring mill test or vertical turret lathe test;

FIG. 4 shows a drop tower apparatus for testing impact resistance of superhard components using a "drop hammer" test;

FIG. 5 shows a perspective view of an acoustic emission testing system in accordance with an exemplary embodiment of the present invention;

FIG. 6 shows a cross-sectional view of the acoustic emission testing device of FIG. 5 in accordance with an exemplary embodiment of the present invention;

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FIG. 7 shows a perspective view of a cutter holder, as shown in FIG. 5, in accordance with an exemplary embodiment of the present invention;

FIG. 8 shows a perspective view of the acoustic emission testing device of FIG. 5 with the indenter being removed from the cutter holder in accordance with an exemplary embodiment of the present invention;

FIG. 9 shows a perspective view of an acoustic emission testing system in accordance with an alternative exemplary embodiment of the present invention;

FIG. 10 shows a schematic block diagram of a data recorder of FIG. 5 in accordance with an exemplary embodiment;

FIG. 11 shows a graphical cutter acoustic emission and loading representation for a cutter experiencing a load of up to about two kilonewtons in accordance with an exemplary embodiment of the present invention;

FIG. 12 shows a graphical cutter acoustic emission and loading representation for a cutter experiencing a load of up to about five kilonewtons in accordance with an exemplary embodiment of the present invention;

FIG. 13 shows a graphical cutter acoustic emission and loading representation for a cutter experiencing a load of up to about thirty kilonewtons in accordance with an exemplary embodiment of the present invention;

FIG. 14 shows a graphical cutter acoustic emission and loading representation for a cutter experiencing a load of up to about forty kilonewtons in accordance with an exemplary embodiment of the present invention;

FIG. 15A shows a graphical cutter acoustic emission and loading representation for a cutter manufacturer #1 cutter sample #1 cutter type experiencing a load of up to about forty-five kilonewtons in accordance with an exemplary embodiment of the present invention;

FIG. 15B shows a graphical cutter acoustic emission and loading representation for a cutter manufacturer #2 cutter sample #2 cutter type experiencing a load of up to about thirty kilonewtons in accordance with an exemplary embodiment of the present invention;

FIG. 16 illustrates a flowchart of a method for analyzing data points received from the acoustic sensor, wherein the method includes a loop one method and a loop two method in accordance with an exemplary embodiment of the present invention;

FIG. 17 illustrates a detailed flowchart of the loop one method of FIG. 16 in accordance with an exemplary embodiment of the present invention;

FIG. 18 illustrates a detailed flowchart of the loop two method of FIG. 16 in accordance with an exemplary embodiment of the present invention;

FIG. 19 shows a graphical cutter acoustic emission representation for a cutter experiencing a load in accordance with an exemplary embodiment of the present invention;

FIG. 20 shows a magnified view of a portion of a graphical cutter acoustic emission representation for a cutter experiencing a load in accordance with an exemplary embodiment of the present invention;

FIG. 21 shows a cumulative distribution representation for each actual acoustic event in accordance with an exemplary embodiment of the present invention;

FIG. 22 shows a block diagram of the processor of FIG. 10 in accordance with an exemplary embodiment;

FIG. 23 shows a rock sample that is testable within the acoustic emission testing systems of FIGS. 5 and 9, respectively, in lieu of the cutter of FIG. 1 in accordance with an exemplary embodiment;

FIG. 24 shows the acoustic emission testing device of FIG. 5 inserted within a pressurizable chamber in accordance with an exemplary embodiment;

FIG. 25 shows a cross-sectional view of an acoustic emission testing system in accordance with an exemplary embodiment of the present invention;

FIG. 26 shows a cross-sectional view of an acoustic emission testing system in accordance with another exemplary embodiment of the present invention;

FIG. 27 shows an acoustic testing method in accordance with an exemplary embodiment of the present invention;

FIG. 28 shows a cross-sectional view of an acoustic emission testing system in accordance with yet another exemplary embodiment of the present invention;

FIG. 29 shows a side schematic view of an acoustic emission formation sampling tool in an operating position within a wellbore in accordance with another exemplary embodiment of the present invention;

FIG. 30 shows a top schematic view of an acoustic emission formation sampling tool in an operating position within a wellbore in accordance with another exemplary embodiment of the present invention;

FIG. 31 shows a side schematic view of an acoustic emission formation sampling tool in an operating position within a wellbore in accordance with another exemplary embodiment of the present invention; and

FIG. 32 illustrates a flowchart of a method for determining one or more properties of a rock formation located within a wellbore using the acoustic emission formation sampling tool in accordance with an exemplary embodiment of the present invention.

The drawings illustrate only exemplary embodiments of the invention and are therefore not to be considered limiting of its scope, as the invention may admit to other equally effective embodiments.

#### BRIEF DESCRIPTION OF EXEMPLARY EMBODIMENTS

The present invention is directed to a method, apparatus, and software for testing the intrinsic strength, or toughness, of hard or superhard materials, such as inserts and rock samples obtained from a down hole formation, using acoustic emissions. Although the description of exemplary embodiments is provided below in conjunction with a PDC cutter, alternate embodiments of the invention may be applicable to other types of hard or superhard materials including, but not limited to, PCBN cutters, rock samples, or other hard or superhard materials known or not yet known to persons having ordinary skill in the art. For example, the hard or superhard materials include cemented tungsten carbide, silicon carbide, tungsten carbide matrix coupons, ceramics, or chemical vapor deposition ("CVD") coated inserts. The hard or superhard materials also include rock samples that include, but are not limited to, hard rock samples and/or cemented rock samples obtained from a down hole formation or drill hole. According to some exemplary embodiments of the present invention, one or more properties of a rock sample is determined by measuring the fracture events occurring within the rock sample when subjected to fracture-causing pressures. In certain exemplary embodiments, the fracture events are measured over time and space. Measuring at least the intensity and/or the locations of the fractures within the rock sample facilitate in selecting the appropriate cutter types to be used for the drilling application according to some exemplary embodiments. In some exemplary embodiments, measuring at least the intensity and/or the locations of the fractures within the rock sample facilitate

in selecting at least one parameter of a high pressure down hole fracturing program or at least one parameter of a down hole drilling program targeted to the down hole formation or similar down hole formations from which the rock sample was obtained. In some exemplary embodiments, measuring at least the intensity and/or the locations of fractures within the rock sample facilitate in selecting at least one parameter of a perforating program for explosive, bullet, abrasive, or hydraulic jet perforating through a liner and into the formation to be produced. In some exemplary embodiments, measuring at least the intensity and/or the locations of fractures within the rock sample facilitate a correlation to rock porosity. In some exemplary embodiments, measuring at least the intensity and/or the locations of fractures within the rock sample facilitate a direct measurement of rock density. In some exemplary embodiments, measuring at least the intensity and/or the locations of fractures within the rock sample facilitate the design of a well completion program.

The invention is better understood by reading the following description of non-limiting, exemplary embodiments with reference to the attached drawings, wherein like parts of each of the figures are identified by like reference characters, and which are briefly described as follows. FIG. 5 shows a perspective view of an acoustic emission testing system 500 in accordance with an exemplary embodiment of the present invention. FIG. 6 shows a cross-sectional view of the acoustic emission testing device 505 of FIG. 5 in accordance with an exemplary embodiment of the present invention. Referring to FIGS. 5 and 6, the acoustic emission testing system 500 includes an acoustic emission testing device 505 communicably coupled to a data recorder 590. The acoustic emission testing device 505 includes a cutter holder 510, the cutter 100, an indenter 550, and an acoustic sensor 570. In certain embodiments, however, the cutter holder 510 is optional. Although the cutter 100 is depicted in the exemplary embodiment, a rock sample 2300 (FIG. 23) replaces the cutter 100 in alternative exemplary embodiments.

FIG. 7 shows a perspective view of the cutter holder 510 in accordance with an exemplary embodiment of the present invention. Referring to FIGS. 5, 6, and 7, the cutter holder 510 includes first surface 712, a second surface 714, and a side surface 716. The first surface 712 is disposed in a plane that is substantially parallel to the plane that the second surface 714 is disposed. The side surface 716 extends from the first surface 712 to the second surface 714. According to some exemplary embodiments, the side surface 716 is substantially perpendicular to at least one of the first surface 712 and the second surface 714. According to alternative exemplary embodiments, the side surface 716 is not substantially perpendicular to either the first surface 712 or the second surface 714. The cutter holder 510 is fabricated from steel; however, according to other exemplary embodiments, the cutter holder 510 is fabricated from any metal, wood, or other suitable material known to people having ordinary skill in the art that is capable of withstanding a load 580, which is described in further detail below, that is to be applied. The load 580 can range from about zero kilonewtons to about seventy kilonewtons. In certain exemplary embodiments, the suitable material is capable of being machined or molded and is capable of propagating sound. In certain exemplary embodiments, the suitable material is capable of propagating sound at a speed of about 1 kilometers per second or higher.

The cutter holder 510 is shaped in a substantially cylindrical shape, wherein the first surface 712 is substantially circular shaped, the second surface is substantially circular shaped, and the side surface 716 is substantially arcuate shaped. However, the side surface 716 includes a coupling portion 730,



which is substantially planar, or flat-surfaced, and extends from the first surface 712 to the second surface 714. The coupling portion 730 provides a surface for coupling the acoustic sensor 570 to the cutter holder 510. In certain exemplary embodiments, the coupling portion 730 does not extend the entire length from the first surface 712 to the second surface 714. In some exemplary embodiments, the acoustic sensor 570 is sized such that the acoustic sensor 570 is able to be coupled to the side surface 716 that is arcuate shaped. Thus, the coupling portion 730 is optional in those exemplary embodiments. Although one exemplary shape is provided for the cutter holder 510, the cutter holder 510 can be shaped into any other geometric or non-geometric shape, such as square shaped cylinder or triangular shaped cylinder, without departing from the scope and spirit of the exemplary embodiment.

A cavity 720 is formed within the cutter holder 510 and is sized to receive the cutter 100, or some other hard or superhard material such as a rock sample 2300 (FIG. 23), which is further described below. The cavity 720 is sized slightly larger in diameter than the diameter of the cutter 100, thereby allowing the cutter 100 to easily and freely fit within the cavity 720. The cavity 720 extends from the first surface 712 towards the second surface 714, but does not reach the second surface 714. In other exemplary embodiments, the cavity 720 extends from the first surface 712 to the second surface 714 and proceeds through the cutter holder 510, thereby forming a hole within the cutter holder 510. The cavity 720 is circular in shape, but is any other geometric or non-geometric shape in other exemplary embodiments. The cavity 720 is formed by machining the cutter holder 510 or molding the cutter holder 510 to have the cavity 720 formed therein. Alternatively, the cavity 720 is formed using other methods known to people having ordinary skill in the art. In certain exemplary embodiments, the cavity 720 is formed in a manner to ensure that the cutter 100 is properly aligned in the same manner each time the cutter 100 is inserted within the cavity 720.

The cutter 100 has been previously described with respect to FIG. 1 and is applicable to the exemplary embodiments. Briefly, the cutter 100 includes the substrate 110 and the cutter table 120, which is formed or coupled to the top of the substrate 110. In the exemplary embodiment, the cutter table 120 is formed from PCD, but alternative exemplary embodiments have the cutter table 120 fabricated from other materials, such as PCBN, without departing from the scope and spirit of the exemplary embodiment. Although cutter 100 has a planar cutter table 120, or is flat-faced, the cutter table 120 can be dome shaped, concave shaped, or any other shape known to people having ordinary skill in the art.

The cutter 100 includes finished and/or grounded cutters as well as “raw” cutters. “Raw” cutters are unfinished and are cutters that are typically available right out of a pressing cell. Embodiments of the present invention allow testing of both these cutter types. Since cutter manufacturers are able to test “raw” cutters in accordance with embodiments of the present invention, cutter manufacturers are able to insure that they are meeting specification early in a cutter production run. If cutter manufacturers determine that the “raw” cutters 100 are not meeting appropriate specifications, they are able to make the necessary changes in their operating parameters to get “good” cutters before continuing on with the cutter production run. Additionally, “raw” cutters are capable of being tested at a lower kilonewton level, or load, to insure that the “raw” cutters are not cracking under the given load. If cracks are occurring during the testing of the “raw” cutters, cutter manufacturers can forgo the additional expenses associated with finishing and grinding these “raw” cutters; thereby saving unnecessary cost expenditures. Hence, each “raw” cutter is

capable of being tested through the acoustic emission testing system 500 using lower load levels to insure that the cutters 100 are “good” cutters.

Referring to FIG. 6, the cutter 100 is inserted within the cavity 720 of the cutter holder 510. The cutter 100 is oriented within the cavity 720 so that the cutter table 120 is facing towards the first surface 712, or away from the second surface 714. According to this exemplary embodiment, the entire cutter 100 is inserted within the cavity 720. However, in alternative exemplary embodiments, a portion of the cutter 100, which includes the entire substrate 110, is completely inserted within the cavity 720. Thus, in these alternative exemplary embodiments, at least a portion of the cutter table 120 is not inserted within the cavity 720. Once the cutter 100 has been inserted within the cavity 720, an air gap 610 is formed between the outer perimeter of the cutter 100 and the outer surface of the cavity 720. According to certain exemplary embodiments, a lubricant 620 is applied to the outer perimeter of the cutter 100 or placed within the cavity 720. In these exemplary embodiments, once the cutter 100 is placed within the cavity 720, the lubricant 620 fills at least a portion of the air gap 610 such that the lubricant 620 adheres to both the outer surface of the cavity 720 and the outer perimeter of the cutter 100 and occupies the portion of the air gap 610 therebetween. In other exemplary embodiments, the lubricant 620 is placed at least between the bottom surface of the cavity 720 and the base of the cutter 100. The lubricant 620 improves acoustic transmission between the cutter 100 and the acoustic sensor 570. The lubricant 620 is a gel, such as an ultrasound gel, according to some exemplary embodiments. However, in alternative exemplary embodiments, other materials can be used as the lubricant 620, which includes, but is not limited to, oils, greases, and lotions. These materials are capable of being spread, adhering to surfaces, and not rapidly drying out. Although the cutter 100 is described as being used in this exemplary embodiment, other hard or superhard materials that desire a toughness testing can be used in lieu of the cutter 100.

Referring back to FIGS. 5 and 6, the indenter 550 is dome shaped at a first end 650 and has a planar surface at a second end 652. The indenter 550 is fabricated to be tougher than the cutter 100 so that once load 580 is applied to the indenter 550, it is the cutter 100 that is damaged and not the indenter 550. For example, the indenter 550 is fabricated from tungsten carbide-cobalt; however, other materials known to those having ordinary skill in the art can be used to fabricate the indenter 550. In certain exemplary embodiments, the cobalt content of the indenter 550 ranges from about six percent to about twenty percent. In certain exemplary embodiments, the cobalt content of the indenter 550 is greater than the cobalt content of the cutter table 120 of the cutter 100. Additionally, in certain exemplary embodiments, a PCD layer is formed or mounted onto the first end 650 of the indenter 550. In these embodiments, the cobalt content of the PCD layer of the indenter 550 is greater than the cobalt content of the cutter table 120 of the cutter 100. Also, in these exemplary embodiments, the cobalt content of the PCD layer of the indenter 550 ranges from about six percent to about twenty percent. Although cobalt is used in these exemplary embodiments to make the indenter tougher than the cutter 100, other components known to people having ordinary skill in the art can be used in alternative exemplary embodiments.

The indenter 550 is sized to fit within the cavity 720 so that it makes contact with the cutter 100. In certain exemplary embodiments, the perimeter of the indenter 550 is sized substantially similar to the perimeter of the cavity 720. However, in the exemplary embodiments where at least a portion of the

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cutter table **120** is not within the cavity **720**, the indenter **550** can be dimensioned such that the perimeter of the indenter **550** is greater than the perimeter of the cavity **720**. The indenter **550** is oriented so that the first end **650** makes contact with the cutter **100**. Thus, in this embodiment, the PDC layer of the indenter **550** makes contact with the PDC layer, or cutter table **120**, of the cutter **100**. The load **580** is applied to the second end **652**, which transmits the load **580** onto the cutter **100**. Although a dome shaped indenter **550** is used in these exemplary embodiments, other exemplary embodiments can use indenters having other shapes, such as a cylindrical shape having a substantially planar surface at both the first end **650** and the second end **652**. Also, the second end **652** can be formed into other non-planar shapes without departing from the scope and spirit of the exemplary embodiments.

The acoustic sensor **570** is a piezoelectric sensor that is positioned along the coupling portion **730** of the cutter holder **510**. However, the acoustic sensor **570** can be any other device type known to people having ordinary skill in the art, wherein the device is capable of detecting acoustic transmissions. The acoustic sensor **570** detects elastic wave signals formed in the cutter **100**, which then converts the elastic waves signal to a voltage signal so that the data can be recorded and subsequently analyzed. In certain exemplary embodiments, the lubricant **620** is placed at the contact area between the coupling portion **730** and the acoustic sensor **570**. As previously mentioned, the lubricant **620** improves detection of elastic wave transmission from the cutter **100** to the acoustic sensor **570**. According to some alternative exemplary embodiments, the acoustic sensor **570** is sized so that it is capable of being placed on the arcuate portion of the side surface **716**. The acoustic sensor **570** is communicably coupled to the data recorder **590** so that the voltage signal derived from the elastic waves occurring within the cutter **100** can be stored and subsequently analyzed. The acoustic sensor **570** is coupled to the data recorder **590** using a cable **592**; however, according to other exemplary embodiments, the acoustic sensor **570** can be communicably coupled to the data recorder **590** wirelessly using wireless technology including, but not limited to, infrared and radio frequency.

The data recorder **590** records the data sent from the acoustic sensor **570** and stores the data therein. In certain exemplary embodiments, the apparatus (not shown), or machine, delivering the load **580** also is coupled to the data recorder **590** using a cable **582**; however, according to other exemplary embodiments, the apparatus delivering the load **580** can be communicably coupled to the data recorder **590** wirelessly using wireless technology including, but not limited to, infrared and radio frequency. The data recorder **590** also processes and analyzes the data that it receives.

FIG. **10** shows a schematic block diagram of a data recorder **590** of FIG. **5** in accordance with an exemplary embodiment. Referring to FIGS. **5** and **10**, the data recorder **590** is a computer system. The data recorder **590** includes a storage medium **1040**, a user interface **1030**, a processor **1020**, and a display **1010**.

The storage medium **1040** receives information from the acoustic sensor **570** (FIG. **5**) and records the information therein. The storage medium **1040** is a hard drive according to one exemplary embodiment. However, according to other exemplary embodiments, the storage medium **1040** includes at least one of a hard drive, a portable hard drive, a USB drive, a DVD, a CD, or any other device capable of storing data and/or software. In some exemplary embodiments, the storage medium **1040** also includes a software for providing instructions on how to process the information, or data, received from the acoustic sensor **570** (FIG. **5**).

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The user interface **1030** allows a user to interface with the data recorder **590** and provide instructions for operating the data recorder **590**. According to some exemplary embodiments, the user interface includes a keyboard. However, according to other exemplary embodiments, the user interface includes at least one of a keyboard, a mouse, a touch screen which can be part of the display **1010**, or any other user interface known to people having ordinary skill in the art.

The processor **1020** is capable of receiving instructions from the user interface **1030**, accessing information stored within the storage medium **1040**, sending information to the storage medium **1040**, and sending information to the display **1010**. In some exemplary embodiments, the processor **1020** accesses the software that resides within the storage medium **1040** and executes the set of instructions provided by the software. A more detailed description of these instructions are provided further below. In some exemplary embodiments, the processor **1020** includes processor engines **2200**, which are described in further detail below in conjunction with FIGS. **16**, **17**, **18**, and **22**.

The display **1010** receives information from the processor and communicates this information to the user. According to one exemplary embodiment, the display **1010** includes a monitor, or screen. However, according to other exemplary embodiments, the display **1010** includes at least one of a screen, a touch screen, a printer, or any other device capable of communicating information to the user.

Although not illustrated in FIG. **10**, the data recorder **590** can be communicably coupled, either wired or wirelessly, to an internal network, wherein the software and/or data from the acoustic sensor **570** (FIG. **5**) is stored in a central server (not shown). Additionally, according to some alternative exemplary embodiments, the data recorder **590** can be communicably coupled, either wired or wirelessly, to a modem (not shown), wherein the modem is communicably coupled to the world wide web. In certain alternative exemplary embodiments, the software and/or data from the acoustic sensor **570** (FIG. **5**) is stored in a remote location that is accessible via the world wide web.

FIG. **8** shows a perspective view of the acoustic emission testing device **505** of FIG. **5** with the indenter **550** being removed from the cutter holder **510** in accordance with an exemplary embodiment of the present invention. Referring to FIG. **8**, the cutter **100** is fully inserted within the cavity **720** of the cutter holder **510**. As shown, the diameter of the cutter **100** is less than the diameter of the cavity **720**, thereby forming the air gaps **610**. Also, the PDC layer, or the cutter table **120**, is oriented within the cavity **720** so that the PCD layer faces towards the first surface **712**. The indenter **550** is removed from the cavity **720** to further illustrate some features of the indenter **550**. According to this exemplary embodiment, the indenter **550** includes a substrate **808** and a hard surface **810**, which is formed or coupled to the top of the substrate **808**. In the exemplary embodiment, the hard surface **810** is formed from PCD, but alternative exemplary embodiments can have the hard surface **810** fabricated from other hard or superhard materials, such as PCBN, without departing from the scope and spirit of the exemplary embodiment. Although indenter **550** has a dome shaped hard surface **810**, the hard surface **810** can be planar or any other shape known to people having ordinary skill in the art. As seen, the indenter **550** has a diameter substantially similar to the diameter of the cavity **720**, according to this exemplary embodiment.

In an alternative embodiment, the indenter **550** is positioned within the cavity **720** having the hard surface **810** facing towards the first surface **712**. The cutter **100** to be tested is positioned on top of the indenter **550** with the cutter

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table 120 contacting the hard surface 810. The load 580 is applied downward on the back face of the substrate 110 of the test cutter 100. Acoustic emissions of cracks initiated and/or propagated in the test cutter 100 is transmitted through the indenter 550 and to the acoustic sensor 570. In this alternative exemplary embodiment, the cutter holder 510 is optional.

FIG. 9 shows a perspective view of an acoustic emission testing system 900 in accordance with an alternative exemplary embodiment of the present invention. Referring to FIG. 9, the acoustic emission testing system 900 includes an acoustic emission testing device 905 communicably coupled to the data recorder 507. The acoustic emission testing device 905 is similar to the acoustic emission testing device 505 of FIG. 5, except that the acoustic sensor 570 is directly coupled to the cutter 100 and the cutter holder 510 of FIG. 5 is removed. The cutter 100, the indenter 550, the load 580, the acoustic sensor 570, and the data recorder 590 have been previously described with respect to FIGS. 5, 6, 7, 8, and 10. Also, the lubricant 620 (FIG. 6) is placed between the acoustic sensor 570 and the cutter 100 according to some exemplary embodiments.

The operation of the acoustic emission testing system 500 is described while referring to FIGS. 5-8. The cutter 100, or hard or superhard material, to be tested is placed within the cavity 720 of the cutter holder 510. To improve the elastic wave transmission across the contacting surfaces between the base, or bottom surface, of the cutter 100 and the base of the cavity 720, a mineral oil based gel 620 is used between the bottom surface of the cutter 100 and the base of the cavity 720. The acoustic sensor 570 is positioned against the coupling portion 730 of the cutter holder 510 to detect the elastic waves generated within the cutter 100. To improve the elastic wave transmission across the contacting surfaces between the acoustic sensor 570 and the coupling portion 730, the mineral oil based gel 620 also is used between the acoustic sensor 570 and the coupling portion 730. The indenter 550 is placed on top of the PCD layer 120 of the cutter 100 and is pushed against this PCD layer 120 using the load 580. The load 580 is provided on the indenter 550 using a 100 kilonewton 8500 series Instron machine. This machine (not shown) is capable of controlling the amount of load that is exerted on the indenter 550. The machine is hooked up to the data recorder 590 so that load versus time is measured. Although one example of a machine capable of providing the load 580 is disclosed, any system capable of providing a measurable load to the indenter 550 is in the scope of exemplary embodiments for this invention. For example, the machine or apparatus for delivering the measurable load 580 can range from a hand-held hammer to a fully instrumented impact machine or to a load controlled hydraulic machine for steady ramp or cyclic loading histories.

The load 580 is applied onto the indenter 550 and increased at a constant rate to a desired load level. Once reaching the desired load level, the load level is maintained for a desired period of time, which can range from a few seconds to several minutes, and then ramped down at a faster rate than the ramp up rate. Each time a new crack forms or an existing crack grows within the top diamond layer 130, a certain amount of elastic energy is released almost instantaneously in the form of a train of elastic waves travelling through the PCD layer 120, the substrate 110, and the cutter holder 510. The acoustic sensor 570 detects these elastic waves and converts the received signals into a voltage signal. The acoustic sensor 570 is communicably coupled to the data recorder 590 so that acoustic emissions, or data, are recorded against time. These acoustic emissions include background noise and acoustic events. Hence, since the acoustic emissions history and the

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loading history is recorded onto the data recorder 590, one can determine at what load 580 certain acoustic events occurred. An acoustic event is an event where a new crack forms or when an existing crack grows in the PDC layer 120. According to one exemplary embodiment, the acoustic sensor 570 provides data to the data recorder 590 at about 5,000 data points per second; however, the data points per second can be increased or decreased without departing from the scope and spirit of the exemplary embodiment.

FIG. 11 shows a graphical cutter acoustic emission and loading representation 1100 for a cutter experiencing a load of up to about two kilonewtons in accordance with an exemplary embodiment of the present invention. Referring to FIG. 11, the cutter acoustic emission and loading representation 1100 includes a time axis 1110, a load axis 1120, and an acoustic emissions axis 1130. The time axis 1110 is represented by an x-axis and is provided with units in the seconds times 5,000. Thus, to obtain the time period in seconds, the numerical value in the time axis 1110 is to be divided by 5,000. The time axis 1110 can also be read as energy being delivered to the sample. In other words, as more time passes, more total energy is exerted on the cutter or test sample. The load axis 1120 is represented by a y-axis and is provided with units in the kilonewtons. The acoustic emissions axis 1130 also is represented by the y-axis and is provided with units in the millivolts times ten. Thus, to obtain the voltage in millivolts, the numerical value in the acoustic emissions axis 1130 is to be divided by ten. A load curve 1140 and an acoustic emissions curve 1160 are both illustrated on the cutter acoustic emission and loading representation 1100. According to the load curve 1140, the load was increased from zero kilonewtons to two kilonewtons at a constant rate 1142, or ramp up rate. The load was held at a peak load level 1143, or two kilonewtons in this example, for a period of time and then ramped down at a ramp down rate 1144, which is faster than the ramp up rate 1142. The acoustic emissions curve 1160 represents the recorded signal from the acoustic sensor. According to the acoustic emissions curve 1160, the only acoustic emissions recorded is a background noise 1162. There were no acoustic events that were detected. Also, as the load increases, the background noise 1162 also increases.

FIG. 12 shows a graphical cutter acoustic emission and loading representation 1200 for a cutter experiencing a load of up to about five kilonewtons in accordance with an exemplary embodiment of the present invention. Referring to FIG. 12, the cutter acoustic emission and loading representation 1200 includes a time axis 1210, a load axis 1220, and an acoustic emissions axis 1230. The time axis 1210 is represented by an x-axis and is provided with units in the seconds times 5,000. Thus, to obtain the time period in seconds, the numerical value in the time axis 1210 is to be divided by 5,000. The time axis 1210 can also be read as energy being delivered to the sample. In other words, as more time passes, more total energy is exerted on the cutter or test sample. The load axis 1220 is represented by a y-axis and is provided with units in the kilonewtons. The acoustic emissions axis 1230 also is represented by the y-axis and is provided with units in the millivolts times ten. Thus, to obtain the voltage in millivolts, the numerical value in the acoustic emissions axis 1230 is to be divided by ten. A load curve 1240 and an acoustic emissions curve 1260 are both illustrated on the cutter acoustic emission and loading representation 1200. According to the load curve 1240, the load was increased from zero kilonewtons to five kilonewtons at a constant rate 1242, or ramp up rate. The load was held at a peak load level 1243, or five kilonewtons in this example, for a period of time and then ramped down at a ramp down rate 1244, which is faster than

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the ramp up rate **1242**. The acoustic emissions curve **1260** represents the recorded signal from the acoustic sensor. According to the acoustic emissions curve **1260**, the only acoustic emissions recorded is a background noise **1262**. There were no acoustic events that were detected. Also, as the load increases, the background noise **1262** also increases.

FIG. **13** shows a graphical cutter acoustic emission and loading representation **1300** for a cutter experiencing a load of up to about thirty kilonewtons in accordance with an exemplary embodiment of the present invention. Referring to FIG. **13**, the cutter acoustic emission and loading representation **1300** includes a time axis **1310**, a load axis **1320**, and an acoustic emissions axis **1330**. The time axis **1310** is represented by an x-axis and is provided with units in the seconds times 5,000. Thus, to obtain the time period in seconds, the numerical value in the time axis **1310** is to be divided by 5,000. The time axis **1310** can also be read as energy being delivered to the sample. In other words, as more time passes, more total energy is exerted on the sample. The load axis **1320** is represented by a y-axis and is provided with units in the kilonewtons. The acoustic emissions axis **1330** also is represented by the y-axis and is provided with units in the millivolts times ten. Thus, to obtain the voltage in millivolts, the numerical value in the acoustic emissions axis **1330** is to be divided by ten. A load curve **1340** and an acoustic emissions curve **1360** are both illustrated on the cutter acoustic emission and loading representation **1300**. According to the load curve **1340**, the load was increased from zero kilonewtons to thirty kilonewtons at a constant rate **1342**, or ramp up rate. The load was held at a peak load level **1343**, or thirty kilonewtons in this example, for a period of time and then ramped down at a ramp down rate **1344**, which is faster than the ramp up rate **1342**. The acoustic emissions curve **1360** represents the recorded signal from the acoustic sensor. According to the acoustic emissions curve **1360**, the acoustic emissions recorded includes a background noise **1362** and one or more acoustic events **1364**. The background noise **1362** makes up the bulk of the data recorded during the test. The acoustic events **1364** are shown as thin vertical lines that significantly extend upwards from the background noise **1362**. The height of each acoustic event **1364** above the background noise **1362** is proportional to the amount of elastic energy released by each cracking formation and/or propagation event by means of a calibration constant. Every single acoustic event **1364** lasts on average about fifty milliseconds. According to this exemplary embodiment, the acoustic sensor samples about 5,000 data points per second, which allows detection of these acoustic events **1364**. Also, as the load increases, the background noise **1362** also increases. After completing this test, the cutter was visually examined. Although there were no visual signs of any damage on the top PCD surface of the cutter, the acoustic sensor did detect acoustic events occurring within the cutter. Thus, the acoustic sensor is able to detect minimal damage occurring to the cutters once exposed to a load even though the damage is not visible.

FIG. **14** shows a graphical cutter acoustic emission and loading representation for a cutter experiencing a load of up to about forty kilonewtons in accordance with an exemplary embodiment of the present invention. The same cutter sample used in the tests represented in FIG. **13** was used in the test represented in FIG. **14**. Referring to FIG. **14**, the cutter acoustic emission and loading representation **1400** includes a time axis **1410**, a load axis **1420**, and an acoustic emissions axis **1430**. The time axis **1410** is represented by an x-axis and is provided with units in the seconds times 5,000. Thus, to obtain the time period in seconds, the numerical value in the time axis **1410** is to be divided by 5,000. The time axis **1410**

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can also be read as energy being delivered to the sample. In other words, as more time passes, more total energy is exerted on the sample. The load axis **1420** is represented by a y-axis and is provided with units in the kilonewtons. The acoustic emissions axis **1430** also is represented by the y-axis and is provided with units in the millivolts times ten. Thus, to obtain the voltage in millivolts, the numerical value in the acoustic emissions axis **1430** is to be divided by ten. A load curve **1440** and an acoustic emissions curve **1460** are both illustrated on the cutter acoustic emission and loading representation **1400**. According to the load curve **1440**, the load was increased from zero kilonewtons to forty kilonewtons at a constant rate **1442**, or ramp up rate. The load was held at a peak load level **1443**, or forty kilonewtons in this example, for a period of time and then ramped down at a ramp down rate **1444**, which is faster than the ramp up rate **1442**. The acoustic emissions curve **1460** represents the recorded signal from the acoustic sensor. According to the acoustic emissions curve **1460**, the acoustic emissions recorded includes a background noise **1462** and one or more acoustic events **1464**. The acoustic events **1464** are shown as vertical lines that significantly extend upwards from the background noise **1462**. The height of each acoustic event **1464** above the background noise **1462** is proportional to the amount of elastic energy released by each cracking formation and/or propagation event by means of a calibration constant. As seen in FIG. **14**, acoustic events **1464** did not occur within the cutter until the load reached or exceeded the previous load that was exposed to this cutter. For example, this cutter previously experienced loads up to thirty kilonewtons as described in FIG. **13**. Thus, new acoustic events **1464** did not arise until the load reached and/or exceeded a threshold **1466**, which was about thirty kilonewtons in this example, that was previously applied on to the cutter. Based upon the experiments, it seems that to generate new cracks or to grow existing cracks in the cutter that were formed in a previous test run, a load level equal to or higher than the previous peak load level **1343** is to be applied.

FIG. **15A** shows a graphical cutter acoustic emission and loading representation **1500** for a cutter manufacturer #1 cutter sample #1 cutter type experiencing a load of up to about forty-five kilonewtons in accordance with an exemplary embodiment of the present invention. FIG. **15B** shows a graphical cutter acoustic emission and loading representation **1550** for a cutter manufacturer #2 cutter sample #2 cutter type experiencing a load of up to about thirty kilonewtons in accordance with an exemplary embodiment of the present invention. Referring to FIGS. **15A** and **15B**, the cutter acoustic emission and loading representation **1500** includes an acoustic emission curve **1510** showing one or more acoustic events **1520** occurring within the cutter manufacturer #1 cutter sample #1 cutter type, while the cutter acoustic emission and loading representation **1550** includes an acoustic emission curve **1560** showing one or more acoustic events **1570** occurring within the cutter manufacturer #2 cutter sample #2 cutter type. There are significantly more acoustics events **1520** and **1570** occurring within the cutter manufacturer #2 cutter sample #2 cutter type than in the cutter manufacturer #1 cutter sample #1 cutter type. Thus, different cutter types show different acoustic patterns within their respective acoustic emissions curve. Based upon these results, a user can determine which cutter type is tougher than another cutter type and can thereby rank cutters according to their toughness. In this case, the cutter manufacturer #1 cutter sample #1 cutter type is tougher than the cutter manufacturer #2 cutter sample #2 cutter type.

Based upon the experimental results shown in FIGS. **11-15**, there are at least several observations that can be made.

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First, the acoustic sensor is able to detect crack formation and crack growth within the diamond table of the cutter as the indenter is being loaded and is able to send signals that are subsequently analyzable. Second, different cutter types show different acoustic event patterns and allow a user to rank the toughness of the cutter when compared to another cutter. Third, although there can be no visible damage that is detectable on the surface of the PDC table of the cutter after the test, the acoustic sensor is able to detect any non-visible damage occurring to the cutter.

FIG. 16 illustrates a flowchart of a method 1600 for analyzing data points received from the acoustic sensor, wherein the method includes a loop one method 1680 and a loop two method 1690 in accordance with an exemplary embodiment of the present invention. Although certain steps are shown as proceeding in a particular order, the sequence of steps can be varied without departing from the scope and spirit of the exemplary embodiment. Also, although certain functions are performed in one or more steps, the number of steps for performing that function can be increased or decreased without departing from the scope and spirit of the exemplary embodiment.

Referring to FIG. 16, at step 1605, the method 1600 starts. From step 1605, method 1600 proceed to step 1610. At step 1610, one or more minimum threshold values above the background noise to qualify a data point as a possible acoustic event is determined. Upon completion of step 1610, method 1600 proceeds to step 1615 and step 1625, which can occur simultaneously in certain exemplary embodiments. At step 1615, the background points delimiting the outer envelop of the background noise is determined. At step 1625, the possible acoustic event points is determined based upon the one or more threshold values determined at step 1610. Step 1615 and step 1625 are included in the loop one method 1680, which is described in further detail below in conjunction with FIG. 17.

From step 1615, method 1600 proceeds to step 1620. At step 1620, the background points determined at step 1615 are interpolated to produce a background noise function curve. From steps 1620 and 1625, method 1600 proceeds to step 1630. At step 1630, actual acoustic event points are determined using the possible acoustic event points determined at step 1680 and the background noise function curve determined at step 1620. From step 1630, method 1600 proceeds to step 1635. At step 1635, the amplitude and duration of each actual acoustic event point is determined. From step 1635, method 1600 proceeds to step 1640. At step 1640, the area under each acoustic event point is calculated. From step 1640, method 1600 proceeds to step 1645. At step 1645, the cumulative distribution of the areas is compared to the actual test load for each acoustic event point. A user can use this comparison to make a determination as to the relative toughness of one cutter to another cutter. This comparison allows the determination to be made using a quantitative and objective methods. The duration, amplitude, and frequency of the acoustic event points and the corresponding level of energy, or load, delivered to the sample can be correlated directly with the field impact performance of the PCD, or other hard or super-hard material, being tested. Method 1600 allows measurement of not only the smallest amount of external work, or load, required to initiate some damage but also allows measurement of the amount of additional work, or load, that has to be done to increase the damage level. After step 1645, method 1600 proceed to step 1650 where method 1600 is stopped.

FIG. 19 shows a graphical cutter acoustic emission representation 1900 for a cutter experiencing a load in accordance with an exemplary embodiment of the present invention. FIG.

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20 shows a magnified view of a portion of a graphical cutter acoustic emission representation 2000 for a cutter experiencing a load in accordance with an exemplary embodiment of the present invention. FIG. 21 shows a cumulative distribution representation 2100 for each actual acoustic event in accordance with an exemplary embodiment of the present invention. FIGS. 19-21 depict a majority of the steps illustrated in method 1600 of FIG. 16.

Referring to FIG. 19, the cutter acoustic emission representation 1900 includes a time axis 1910 and an acoustic emissions axis 1930. The time axis 1910 is represented by an x-axis and is provided with units in the seconds times 5,000. Thus, to obtain the time period in seconds, the numerical value in the time axis 1910 is to be divided by 5,000. The acoustic emissions axis 1930 is represented by a y-axis and is provided with units in the millivolts time ten. Thus, to obtain the voltage in millivolts, the numerical value in the acoustic emissions axis 1930 is to be divided by ten. An acoustic emissions data 1960 is illustrated on the cutter acoustic emission representation 1900. The acoustic emissions data 1960 represents the recorded signal from the acoustic sensor. According to the acoustic emissions data 1960, the acoustic emissions data recorded includes one or more background points 1962 and one or more possible acoustic event points 1964. Referring to FIGS. 16 and 19 and according to step 1615 and step 1625 of FIG. 16, the acoustic emissions data 1960 is sorted to include background points 1962 and possible acoustic event points 1964. The sorting of the acoustic emissions data 1960 is performed using an algorithm that resides within data recorder 590 (FIG. 5) according to one exemplary embodiment. However, the algorithm can be stored in another device in alternative exemplary embodiments or is performed manually. Alternatively, other methods known to people having ordinary skill in the art and having the benefit of the present disclosure can be used to categorize the acoustic emissions data 1960. As shown in FIG. 19, each background point 1962 is marked with a circle and each possible acoustic event point 1964 is marked with a square. There are some points that are not defined as either a background point 1962 or a possible acoustic event point 1964. These markings are for illustrative purposes and is not meant to limit the scope of exemplary embodiments of the present invention.

Referring to FIGS. 16 and 19 and according to step 1620 of FIG. 16, a background noise function curve 1970 is interpolated using the determined background points 1962. According to one exemplary embodiment, the background noise function curve 1970 is interpolated using a fourth degree polynomial; however, other degrees of polynomial can be used to interpolate the background points 1962 without departing from the scope and spirit of the exemplary embodiment.

Referring to FIG. 20, a magnified portion of the graphical cutter acoustic emission representation 2000 is presented. According to this figure, each acoustic emissions data 1960, which includes the actual acoustic event points 2010, has a time duration 2020 that it occurs in. Additionally, each actual acoustic event point 2010, has an amplitude 2030 that is measured vertically from the background noise function curve 1970 to the position where the actual acoustic event point 2010 lies. Referring to FIGS. 16 and 20 and according to step 1635 of FIG. 16, the amplitude 2030 and the time duration 2020 of the actual acoustic event point 2010 is calculated. Once the amplitude 2030 and the time duration 2020 is determined, the area 2040 under each actual acoustic event point 2010 is calculated by multiplying the amplitude 2030 to the time duration 2020. This step is accomplished in step

1640 of FIG. 16. According to some of the exemplary embodiments, the units for the area 2040 is millivolt times seconds times 5,000; however, other units can be used without departing from the scope and spirit of the exemplary embodiment.

Referring to FIG. 21, a cumulative distribution representation 2100 for each actual acoustic event is presented. According to this figure, the cumulative distribution representation 2100 includes a load axis 2110 and an acoustic emissions area axis 2130. The load axis 2110 is represented by an x-axis and is provided with units in the kilonewtons. The acoustic emissions area axis 2130 is represented by a y-axis and is provided with units in the millivolts times seconds times fifty thousand. This is the area that is determined that lies under an actual acoustic event point. Thus, to obtain the area in millivolts times seconds, the numerical value in the acoustic emissions area axis 2130 is to be divided by fifty thousand. Referring to FIGS. 16 and 21 and according to step 1645 of FIG. 16, the cumulative distribution of the areas, which is plotted along the acoustic emissions area axis 2130, is compared to the actual test load, which is plotted along the load axis 2110, for each actual acoustic event. The cumulative distribution representation 2100 provides these comparisons for a cutter manufacturer #1 cutter sample #1 cutter plot 2150 and a cutter manufacturer #2 cutter sample #2 cutter plot 2160.

For example, in one of the three cutter manufacturer #1 cutter sample #1 cutter plots 2150, there is an actual acoustic event point at about twenty-eight kilonewtons and at about 3550 millivolt times seconds times 50,000, which is labeled as a Point A 2152. This means that there has been a cumulative area of 3550 millivolt times seconds times 50,000 which has occurred under all previous actual acoustic event points, including the area for the actual acoustic event point that occurred at about a load of about twenty-eight kilonewtons. The next actual acoustic event point, Point B 2154, on that same curve occurs at about 32.5 kilonewtons. The area under that actual acoustic event point is about 650 millivolt times seconds times 50,000, which is not directly shown on the cumulative distribution representation 2100. However, at about 32.5 kilonewtons, there has been a cumulative area of about 4200 millivolt times seconds times 50,000. Thus, about 4200 millivolt times seconds times 50,000 minus about 3550 millivolt times seconds times 50,000 is equal to about 650 millivolt times seconds times 50,000. The harder cutter, or the one that is more intrinsically tougher, provides a curve that has a less cumulative area for a given load. A cutter with a steep curve with a lot of high amplitude actual acoustic event points is less intrinsically tougher than a cutter with a less steep curve and fewer high amplitudes actual acoustic event points. Thus, according to the cumulative distribution representation 2100, a comparison between the cutter manufacturer #1 cutter sample #1 cutter plot 2150 and the cutter manufacturer #2 cutter sample #2 cutter plot 2160 indicates that the cutter manufacturer #1 cutter sample #1 cutter is intrinsically tougher than the cutter manufacturer #2 cutter sample #2 cutter. Also, according to FIG. 21, there are three curves that represent the cutter manufacturer #1 cutter sample #1 cutter plot 2150 and two curves that represent the cutter manufacturer #2 cutter sample #2 cutter plot 2160. These plots 2150 and 2160 illustrate that method 1600 (FIG. 16) has a high resolution so that variabilities within samples of the same group are detectable. The method provided in FIG. 16 provides information to a user for ranking cutter toughnesses amongst other cutters in an objective manner.

FIG. 17 illustrates a detailed flowchart of the loop one method 1680 of FIG. 16 in accordance with an exemplary embodiment of the present invention. Referring to FIG. 17, at

step 1705, the loop one method 1680 starts. From step 1705, loop one method 1680 proceeds to step 1710. At step 1710, the first data point is read. Upon completion of step 1710, loop one method 1680 proceeds to step 1715, where the next data point is read. After step 1715, loop one method 1680 proceeds to step 1720. At step 1720, the difference between the two data points is calculated and compared to a first tolerance value that is used to define an acoustic event. According to one exemplary embodiment, the first tolerance value is about 0.5 millivolts. However, the first tolerance value can be higher or lower in other exemplary embodiments. If the difference between the two data points is not less than the first tolerance value, loop one method 1680 proceeds to step 1725. At step 1725, the second of the two data points is defined as a possible acoustic event point. From step 1725, loop one method 1680 proceeds to step 1745, where loop one method 1680 determines whether there is another data point. If at step 1745, it is determined that there is not another data point, loop one method 1680 proceeds to step 1750, where the loop one method 1680 stops. However, if at step 1745, it is determined that there is another data point, the loop one method 1680 proceeds back to step 1715.

If at step 1720, it is determined that the difference between the two data points is less than the first tolerance value, the loop one method 1680 proceeds to step 1730. At step 1730, the difference between the two data points is compared to a second tolerance value. According to one exemplary embodiment, the second tolerance value is about 0.01 millivolts. However, the second tolerance value can be higher or lower in other exemplary embodiments. If the difference between the two data points is not less than the second tolerance value, loop one method 1680 proceeds back to step 1715 and the second data point is not defined. However, if the difference between the two data points is less than the second tolerance value, loop one method 1680 proceeds to step 1735.

At step 1735, it is determined whether the difference between the two data points is negative and has been negative for less than "z" times in a row or whether the difference is positive and has been positive for less than "u" times in a row. According to one exemplary embodiment, the "z" is two and the "u" is three. However, either or both the "u" value and the "z" value can be higher or lower in other exemplary embodiments. If it is not true that the difference between the two data points is negative and has been negative for less than "z" times in a row or is positive and has been positive for less than "u" times in a row, then the loop one method 1680 proceeds back to step 1715 and the second data point is not defined. However, if the difference between the two data points is negative and has been negative for less than "z" times in a row or is positive and has been positive for less than "u" times in a row, then the loop one method 1680 proceeds to step 1740.

At step 1740, the second of the two data points is defined as a background boundary point. From step 1740, the loop one method 1680 proceeds to step 1745, where it is determined whether there is another data point. The loop one method 1680 continues until step 1750 is reached pursuant to the steps described above. Thus, the loop one method 1680 provides a method for determining which data points should be defined as a possible acoustic event point, a background boundary point, or not defined as either type of point.

FIG. 18 illustrates a detailed flowchart of the loop two method 1690 of FIG. 16 in accordance with an exemplary embodiment of the present invention. Referring to FIG. 18, at step 1805, the loop two method 1690 starts. From step 1805, loop two method 1690 proceeds to step 1810. At step 1810, a background noise function curve is created using the background boundary points. Upon completion of step 1810, loop

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two method 1690 proceeds to step 1815, where the first possible acoustic event point is read. After step 1815, loop two method 1690 proceeds to step 1820. At step 1820, the difference between the possible acoustic event point and the background noise function curve is calculated and determined whether this difference is greater than a third tolerance value that is used to define an actual acoustic event point. According to one exemplary embodiment, the third tolerance value is about 0.08 millivolts. However, the third tolerance value can be higher or lower in other exemplary embodiments. If the difference between the possible acoustic event point and the background noise function curve is not greater than the third tolerance value, loop two method 1690 proceeds to step 1825. At step 1825, the next possible acoustic event point is read and the loop two method 1690 proceeds back to step 1820. However, if the difference between the possible acoustic event point and the background noise function curve is greater than the third tolerance value, loop two method 1690 proceeds to step 1830.

At step 1830, the amplitude, the duration, and the area between the actual acoustic event point and the background noise function curve are calculated. From step 1830, the loop two method 1690 proceeds to step 1840. At step 1840, it is determined whether there is another possible acoustic event point. If there is another possible acoustic event point, the loop two method 1690 proceeds back to step 1825, where the loop two method 1690 continues. However, at step 1840, if there is not another possible acoustic event point, the loop two method 1690 proceeds to step 1845, where the loop two method 1690 stops. Thus, the loop two method 1690 provides a method for determining which data points should be defined as an actual acoustic event point and then calculates the area for each defined acoustic event point.

FIG. 22 illustrates a block diagram of the processor 1020 of FIG. 10 in accordance with an exemplary embodiment. As previously mentioned, the method for performing one or more steps illustrated in FIGS. 16-18 is performed within the processor 1020. However, in certain other exemplary embodiments, these methods are performed manually or a combination of manually and within a processor. The processor 1020 is located within the data recorder 590, or a computer system. Although one processor 1020 is shown, multiple processors can be used without departing from the scope and spirit of the exemplary embodiments. Processor 1020 includes one or more processor engines 2200.

The processor engines 2200 include an acoustic data gathering engine 2210, a background points determination engine 2220, a possible acoustic event points determination engine 2230, a background noise function curve interpolation engine 2240, an actual acoustic event points determination engine 2250, an actual acoustic event area calculation engine 2260, and a cumulative area and load curve engine 2270. Although seven engines are included within the processor engines 2200, the number of engines can be greater or fewer in other exemplary embodiments. Additionally, one or more of these previously mentioned processor engines 2200 can be combined into fewer processor engines 2200 or separated into additional processor engines 2200 without departing from the scope and spirit of the exemplary embodiments.

The acoustic data gathering engine 2210 gathers data from at least the acoustic sensor, which includes background points and possible acoustic event points. The acoustic data gathering engine 2210 also gathers data from the load, in some exemplary embodiments, so that corresponding background points and possible acoustic event points are related to a given load. The background points determination engine 2220 evaluates the data obtained from the acoustic sensor and

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determines whether the data point is a background point. The background points determination engine 2220 performs step 1615 of FIG. 16. The possible acoustic event points determination engine 2230 evaluates the data obtained from the acoustic sensor and determines whether the data point is a possible acoustic event point. The possible acoustic event points determination engine 2230 performs step 1625 of FIG. 16. The background points determination engine 2220 and the possible acoustic event points determination engine 2230 run simultaneously with one another, but can run independently from one another in some alternative exemplary embodiments.

The background noise function curve interpolation engine 2240 generates a background noise function curve using the background points that were previously determined. The background noise function curve interpolation engine 2240 performs step 1620 of FIG. 16. The actual acoustic event points determination engine 2250 determines actual acoustic event points using the possible acoustic event points that were previously determined and the background noise function curve. The actual acoustic event points determination engine 2250 performs step 1630 of FIG. 16. Once the actual acoustic event points are determined, the actual acoustic event area calculation engine 2260 determines the area formed between the actual acoustic event point and the background noise function curve. The actual acoustic event area calculation engine 2260 performs step 1635 and step 1640 of FIG. 16. The cumulative area and load curve engine 2270 compares the cumulative distribution of the areas to the actual test load for each actual acoustic event point. The cumulative area and load curve engine 2270 performs step 1645 of FIG. 16. Although the processor engines 2200 are located in the processor 1020 in some exemplary embodiments, the processor engines 2200 can reside in a storage medium including, but not limited to, one or more hard drives, a USB drive, a compact disc, a digital video disc, or any other storage device known or not yet known to people having ordinary skill in the art.

Although processor engines 2200 are described in the exemplary embodiments, the instructions for determining the toughness of the cutter can be provided in a software that resides within the storage medium 1040 (FIG. 10). The software includes modules and/or code that are similar to the processor engines 2200 described above.

FIG. 23 shows a rock sample 2300 that is testable within the acoustic emission testing systems 500 and 900 of FIGS. 5 and 9, respectively, in lieu of the cutter 100 of FIG. 1 in accordance with an exemplary embodiment. Referring to FIGS. 5, 6, 9, and 23, the rock sample 2300 replaces the cutter 100 in the acoustic emission testing system 500 or the acoustic emission testing system 900. The testing method and analysis of the results are similar to those methods and analysis described above and provides information relating to the unconfined compressive strength and/or toughness of the rock sample 2300.

The rock sample 2300 is cylindrically shaped, which is similar to the cutter 100. The rock sample includes a first planar surface 2310 at one end of the rock sample 2300, a second planar surface 2320 at an opposing end of the rock sample, and a circumferential surface 2330 extending from the first surface 2310 to the second surface 2320. However, in alternative exemplary embodiments, the rock sample 2300 is shaped in other geometric or non-geometric shapes, such as cube-shaped. In certain exemplary embodiments, the shape of the rock sample 2300 is a repeatable shape such that multiple rock samples 2300 are formed with a substantially similar shape; thereby allowing the test results to be comparable.



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FIG. 24 shows the acoustic emission testing device 505 of FIG. 5 inserted within a pressurizable chamber 2410 in accordance with an exemplary embodiment. The pressure within the pressurizable chamber 2410 is variable in a controllable and measurable manner. The pressure within the pressurizable chamber 2410 is variable from zero psi to about 40000 psi in some exemplary embodiments; however, the range of pressures can be higher or lower in other exemplary embodiments. In this exemplary embodiments, other components, including the sensor 570 and the indenter 550, are capable of withstanding the pressures formed within the pressurizable chamber 2410. According to these exemplary embodiments, the rock confined compressive strength and toughness are measurable at different levels of hydrostatic pressures, thereby providing vital information of the rock properties at different depths below the earth surface. The information collected is usable to improve the knowledge of rock failing mechanisms and also lead to new theories and rock solid mechanic models. The information collected also is usable to confirm other known theories not yet proven. Although the pressurizable chamber 2410 is one method for testing the hard or superhard material 100, such as the rock sample 2300, under pressure, other mechanisms for providing pressures on the hard or superhard material 100 can be used, such as using high strength binding rings assembled together and around the hard or superhard material 100, in alternative exemplary embodiments.

The knowledge of the UCS and the toughness of the rock samples 2300 are usable by designers to create new and innovative bit designs having superior performance and/or to develop a new bit design procedure which incorporates the UCS value and the  $K_{1C}$  value. The information obtained from the rock samples 2300 is usable to calibrate geoscience and/or geomechanics software and tools.

Although some exemplary embodiments of the invention have been described, alternative exemplary embodiments include the use of heating the hard or superhard material 100. This heating of the hard or superhard material 100 occurs at either or a combination of before, during, and/or after the application of the load onto the hard or superhard material 100. The heat is supplied in any one of a number of ways known to people having ordinary skill in the art, which include, but is not limited to, flame, laser, infrared, and/or heated liquid.

FIG. 25 shows a cross-sectional view of an acoustic emission testing system 2500 in accordance with an exemplary embodiment of the present invention. Referring to FIG. 25, the acoustic emission testing system 2500 includes an acoustic emission testing device 2505 communicably coupled to an analog-to-digital converter 2592, which is communicably coupled to a data recorder 2590. According to some exemplary embodiments, the analog-to-digital converter 2592 is optional. The acoustic emission testing device 2505 includes a pressurizable chamber 2510, a rock sample 2580, one or more acoustic sensors 2570, a first barrier 2530, a second barrier 2540, and a drain pipe 2595. In some exemplary embodiments, the acoustic emission testing device 2505 also includes one or more couplings 2594 and a drain pipe pressure control valve 2597. Although the rock sample 2580 is depicted in the exemplary embodiment, other types of porous samples can be used in lieu of the rock sample 2580 according to other alternative exemplary embodiments.

The pressurizable chamber 2510 is cylindrically shaped and forms a cavity 2512 therein. However, according to other exemplary embodiments, the pressurizable chamber 2510 is shaped in some other geometric shape, such as a cube-shape, or non-geometric shape. The pressure within the pressuriz-

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able chamber 2510 is variable in a controllable and measurable manner. The pressure within the pressurizable chamber 2510 is variable from zero psi to about 40000 psi in some exemplary embodiments; however, the range of pressures can be higher or lower in other exemplary embodiments. The pressurizable chamber 2510 includes a base 2514 and a sidewall 2516 extending substantially perpendicular around the perimeter of the base 2514. In some alternative exemplary embodiments, the sidewall 2516 extends substantially perpendicular from the base 2514 at a position that is within the perimeter of the base 2514. The pressurizable chamber 2510 is fabricated from steel; however, according to other exemplary embodiments, the pressurizable chamber 2510 is fabricated from any metal, metal alloy, polymer, wood, or other suitable material known to people having ordinary skill in the art that is capable of withstanding at least a second pressure ( $P_0$ ) 2527, which is described in further detail below. In certain exemplary embodiments, the suitable material is capable of being machined or molded and is capable of propagating sound. In certain exemplary embodiments, the suitable material is capable of propagating sound at a speed of about 1 kilometers per second or higher.

The cavity 2512 is formed within the pressurizable chamber 2510 and is sized to receive the entire rock sample 2580, or some other hard or superhard material. The cavity 2512 is sized larger in diameter than the diameter of the rock sample 2580, thereby allowing the rock sample 2580 to easily and freely fit within the cavity 2512. The cavity 2512 is circular in shape, but is any other geometric or non-geometric shape in other exemplary embodiments. The cavity 2512 is formed by machining the pressurizable chamber 2510 or molding the pressurizable chamber 2510 to have the cavity 2512 formed therein. Alternatively, the cavity 2512 is formed using other methods known to people having ordinary skill in the art. In certain exemplary embodiments, the cavity 2512 is formed in a manner to ensure that the rock sample 2580 is properly aligned in the same manner each time the rock sample 2580 is inserted within the cavity 2512. For example, the base 2514 can be keyed to receive the rock sample 2580 in a desired position. For example, the base 2514 includes one or more protrusions (not shown) and/or one or more indentations (not shown) in certain exemplary embodiments.

The rock sample 2580 is a porous material. According to some exemplary embodiments, the rock sample 2580 is formed from a sample of rock obtained from within a drill hole, or wellbore, located at some depth within the wellbore and at a confining pressure. Some examples of rock samples 2580 include, but are not limited to, coal, chalk, shale, limestone, sandstone, all geological formations that include gas or oil, and other known porous rocks. The rock sample 2580 is substantially cylindrical in shape, but can be shaped into other geometric shapes, such as substantially cube-shaped, or non-geometric shapes. The rock sample 2580 includes a top surface 2582, a bottom surface 2584, and a sidewall 2586 extending from the top surface 2582 to the bottom surface 2584. The top surface 2582 and the bottom surface 2584 are substantially parallel to one another; however, according to other exemplary embodiments, the top surface 2582 and the bottom surface 2584 are not parallel to one another. The sidewall 2586 extends substantially perpendicular to both the top surface 2582 and the bottom surface 2584; however, in certain exemplary embodiments, the sidewall 2586 is not perpendicular to at least one of the top surface 2582 and the bottom surface 2584. According to some exemplary embodiments, the sidewall 2586 is arcuate; however, according to some other exemplary embodiments, at least some portions of the sidewall 2586 includes one or more planar surfaces (not



shown). In these exemplary embodiments, these planar surfaces facilitate acoustic sensors 2570 being coupled to the rock sample 2580. The rock sample 2580 is inserted within the cavity 2512 so that the bottom surface 2584 is adjacent to the base 2514. According to some exemplary embodiments, the rock sample 2580 is positioned substantially in the center of the cavity 2512; however, the rock sample 2580 can be positioned off-center of the cavity 2512 in other exemplary embodiments.

The acoustic sensor 2570 is a piezoelectric sensor that is positioned along the sidewall 2586 of the rock sample 2580. However, the acoustic sensor 2570 can be any other device type known to people having ordinary skill in the art, wherein the device is capable of detecting acoustic transmissions. Additionally, according to some exemplary embodiments, the acoustic sensor 2570 is positioned along the exterior portion of the sidewall 2516 of the pressurizable chamber 2510. According to some exemplary embodiments, the acoustic sensor 2570 is sized so that it is capable of being placed on the arcuate portion of the sidewall 2586, 2516. In other exemplary embodiments, the acoustic sensor 2570 is placed on a planar portion (not shown) of the sidewall 2586, 2516. The acoustic sensor 2570 detects elastic wave signals formed in the rock sample 2580, which then converts the elastic waves signal to a voltage signal so that the data can be recorded and subsequently analyzed.

The acoustic sensor 2570 is communicably coupled to the data recorder 2590, via the analog-to-digital converter 2592 in certain exemplary embodiments, so that the voltage signal derived from the elastic waves occurring within the rock sample 2580 can be stored and subsequently analyzed. The data recorder 2590 is similar to the data recorder 590 (FIG. 5) and will not be discussed in detail again. The data recorder 2590 also is set-up similarly to the set-up of data recorder 590 (FIG. 5).

According to the exemplary embodiment illustrated in FIG. 25, there are four acoustic sensors 2570 coupled to the rock sample 2580. However, the number of acoustic sensors 2570 ranges from one acoustic sensor 2570 to any number of acoustic sensors 2570. The acoustic sensors 2570 are able to detect the intensity of acoustic events occurring on or within the rock sample 2580 with respect to time and space. Thus, the location of the acoustic events and the direction in which the cracks are propagating within the rock sample 2580 are determinable. According to some examples, at least one or more acoustic sensors 2570 are positioned at different elevational heights along the sidewall 2586. In one example, three acoustic sensors 2570 are coupled to the rock sample 2580 at different elevational heights along the sidewall 2586. A first acoustic sensor 2570 detects the intensity of the acoustic event occurring within the rock sample 2580 at a first time period and determines the location of the acoustic event occurring within the rock sample 2580 along a first axis, or x-axis. A second acoustic sensor 2570 detects the intensity of the acoustic event occurring within the rock sample 2580 at the first time period and determines the location of the acoustic event occurring within the rock sample 2580 along a second axis, or y-axis. A third acoustic sensor 2570 detects the intensity of the acoustic event occurring within the rock sample 2580 at the first time period and determines the location of the acoustic event occurring within the rock sample 2580 along a third axis, or z-axis. The acoustic sensors 2570 perform the same analysis at a second time period, a third time period, and so forth. Using the speed of sound known within the rock sample 2580, data from the three acoustic sensors 2570 provide information for determining the intensity of the acoustic event occurring within the rock sample 2580, the

location of the acoustic event occurring within the rock sample 2580, and the direction in which the acoustic event is propagating within the rock sample 2580. In the embodiments where the acoustic sensors 2570 are positioned along the pressurizable chamber's sidewall 2516, the speed of sound through a first fluid 2521 and the distance between the respective acoustic sensor 2570 and the rock sample's sidewall 2586 also are used in the determinations. If fewer acoustic sensors 2570 are used, one or more axes are lost for determining where the acoustic event is occurring within the rock sample 2580 along those axes. Each acoustic sensor 2570 represents an axis. When greater than three acoustic sensors 2570 are used, the measurements provide more precise determinations for locating the acoustic events occurring within the rock sample 2580. The data from the three acoustic sensors 2570 are used to triangulate the location of the acoustic event.

The first barrier 2530 is substantially disc-shaped and includes an opening 2532 extending therethrough. The opening 2532 is substantially positioned centrally within the first barrier 2530 and is sized for inserting at least the top surface 2582 within the opening 2532. In some exemplary embodiments, the opening 2532 is used to properly position the rock sample 2580 in the pressurizable chamber 2510. In some exemplary embodiments, the top surface 2582 and at least a portion of the rock sample's sidewall 2586 is inserted through the opening 2532. The opening 2532 is shaped similarly to the shape of at least a portion of a cross-sectional portion of the rock sample's sidewall 2586. Although the first barrier 2530 is substantially disc-shaped, the shape can be any other geometric shape or non-geometric shape that is substantially similar to at least a portion of the cross-sectional shape of the cavity 2512. The first barrier 2530 is fixedly coupled to the interior portion of the sidewall 2516 of the pressurizable chamber 2510, thereby dividing the cavity 2512 into a first chamber 2520 and a second chamber 2525. The first barrier 2530 is coupled to the sidewall 2516 using welding or any other methods known to people having ordinary skill in the art. The weld or any other device used for attaching the first barrier 2530 to the pressurizable chamber's sidewall 2516 is capable of withstanding pressures of at least the second pressure 2527. The first barrier 2530 is fabricated using a metal, metal alloy, polymer, or any other suitable material capable of withstanding pressures of up to at least the second pressure 2527. A first seal 2534 is positioned about the perimeter of the opening 2532 and provides a pressure seal with the rock sample's sidewall 2586. The first seal 2534 is a rubber gasket or any other suitable material known to people having ordinary skill in the art. The pressure within the first chamber 2520 is a first pressure ( $P_1$ ) 2522 which can be different than the second pressure 2527 within the second chamber 2525 during testing, which is described in further detail below. Each of the first pressure 2522 and the second pressure 2527 is variable. Thus, a portion of the rock sample 2580 is exposed to the first pressure 2522 while another portion of the rock sample 2580 is exposed to the second pressure 2527 during testing.

Within the first chamber 2520, the first fluid 2521 is placed. The first fluid 2521 fills up the entire first chamber 2520 in some exemplary embodiments; however, in other exemplary embodiments, the first fluid 2521 fills a portion of the first chamber 2520. The first fluid 2521 is water. However, other types of fluid having similar properties can be used as the first fluid 2521 in other exemplary embodiments. In some exemplary embodiments, the first fluid 2521 includes sand particles or other similar particle types.

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The second barrier **2540** also is substantially disc-shaped and includes a second seal **2542** around the perimeter of the second barrier **2540**. Although the second barrier **2540** is substantially disc-shaped, the shape can be any other geometric shape or non-geometric shape that is substantially similar to at least a portion of the cross-sectional shape of the cavity **2512**. The second barrier **2540** is positioned near the top portion of the pressurizable chamber **2510** within the cavity **2512** and is movably coupled to the interior portion of the sidewall **2516** of the pressurizable chamber **2510**. The second barrier **2540** forms a portion of the second chamber **2525**. The second seal **2542** provides a pressure seal between the second barrier **2540** and the pressurizable chamber's sidewall **2516**. The second seal **2542** is a rubber gasket or any other suitable material known to people having ordinary skill in the art. The second barrier **2540** thereby provides a means for varying the second pressure **2527** within the second chamber **2525**. An external force **2502** is applied on the second barrier **2540** which moves the second barrier **2540** closer to the first barrier **2530**. As the second barrier **2540** moves closer to the first barrier **2520**, the second pressure **2527** increases, and as the second barrier **2540** moves further away from the first barrier **2520**, the second pressure **2527** decreases. The external pressure **2502** is provided by a piston **2503** in some exemplary embodiments; however, the external force **2502** can be provided by any other known methods and/or devices. The second barrier **2540** is fabricated using a metal, metal alloy, polymer, or any other suitable material capable of withstanding pressures of up to at least the second pressure **2527** and/or the external force **2502**, whichever is greater.

Within the second chamber **2525**, a second fluid **2526** is placed. The second fluid **2526** fills up the entire second chamber **2525** in some exemplary embodiments; however, in other exemplary embodiments, the second fluid **2526** fills a portion of the second chamber **2525**. The second fluid **2526** is water. However, other types of fluid having similar properties can be used as the second fluid **2526** in other exemplary embodiments. In some exemplary embodiments, the second fluid **2526** includes sand particles or other similar particle types. According to some exemplary embodiments, the second fluid **2526** is the same as the first fluid **2521**; however, the second fluid **2526** can be different than, but similar in properties to, the first fluid **2521** in other exemplary embodiments. As the second pressure **2527** in the second chamber **2525** increases above the first pressure **2522** in the first chamber **2520**, the second fluid **2526** flows from the second chamber **2525** into the rock sample **2580** and out into the first chamber **2520**. As the second pressure **2527** increases, acoustic events, or cracks, form in the rock sample **2580**. In the exemplary embodiments where sand particles are included in the second fluid **2526**, the sand particles can enter into the cracks formed within the rock sample **2580** and become lodged therein as to prevent the cracks from closing when the second pressure **2527** is decreased.

As the second pressure **2527** increases and the second fluid **2526** flows into the first chamber **2520** through the rock sample **2580**, the first pressure **2522** increases. To maintain the first pressure **2522** constant or substantially constant, a drain pipe **2595** is coupled to the interior of the first chamber **2520** and through the base **2514** to allow the first fluid **2521** and/or the second fluid **2526** that is present within the first chamber **2520** to exit the first chamber **2520**. The drain pipe **2595** is fabricated from a metal, metal alloy, polymer, or other suitable material capable of withstanding the first pressure **2522**. In certain exemplary embodiments, the drain pipe pressure control valve **2597** is installed at a location along the drain pipe **2595** and is configured to be opened and closed,

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either automatically or manually, to maintain the first pressure **2522** at a substantially constant pressure during the testing process. In alternative exemplary embodiments, the drain pipe **2595** is coupled to the interior of the first chamber **2520** through the sidewall **2516**.

The operation of the acoustic emission testing system **2500** is described while referring to FIG. **25**. Once the acoustic emission testing system **2500** is configured according to the description provided above, the drain pipe control valve **2597** is set to maintain the pressure in the first chamber **2520** at the first pressure **2522**. The first pressure **2522** is determined to be the rock confining pressure, which is the pressure at which the rock sample **2580** was exposed to while in the wellbore. The external force **2502** exerted onto the second barrier **2540** is increased, thereby pushing the second barrier **2540** closer towards the first barrier **2530**. This movement of the second barrier **2540** compresses the second fluid **2526**, thereby increasing the second pressure **2527** within the second chamber **2525**. The second pressure **2527** increases to a value above the first pressure **2522** and is ramped up so that acoustic events, or cracking, occurs on or within the rock sample **2580**. The second pressure **2527** is continuously ramped up until the second pressure **2527** reaches a threshold pressure, which is where extensive acoustic events occur within the rock sample **2580**. Once the second pressure **2527** increases above the first pressure **2522**, the second fluid **2526** passes through the porous rock sample **2580** and enters into the first chamber **2520**. The first pressure **2522** would typically increase due to the second fluid **2526** entering the first chamber **2520**; however, the drain pipe control valve **2597** maintains the first pressure **2522** substantially constant and allows the first fluid **2521** and/or the second fluid **2526** that has entered into the first chamber **2520** to exit the first chamber **2520** through the pipe drain **2595**. This threshold pressure that is reached is the pressure that is to be generated in the wellbore for fracing the rock at that confining pressure. During the testing procedure, the acoustic events are measured according to the descriptions provided above. Additionally, the location of the acoustic events are determinable by people having ordinary skill in the art having the benefit of the present disclosure. Moreover, the direction in which the acoustic events are propagating also are determinable by people having ordinary skill in the art having the benefit of the present disclosure. The acoustic sensors **2570** obtain data when the second pressure **2627** is increased. Additionally, in some exemplary embodiments, the acoustic sensors **2570** also obtain data when the second pressure **2627** is decreased after reaching the threshold pressure. Although not illustrated, the first pressure **2522** and the second pressure **2527** are monitored. According to some exemplary embodiments, the second pressure **2527** is recorded.

FIG. **26** shows a cross-sectional view of an acoustic emission testing system **2600** in accordance with another exemplary embodiment of the present invention. Referring to FIG. **26**, the acoustic emission testing system **2600** includes an acoustic emission testing device **2605** communicably coupled to an analog-to-digital converter **2592**, which is communicably coupled to a data recorder **2590**. According to some exemplary embodiments, the analog-to-digital converter **2592** is optional. The acoustic emission testing device **2605** includes a pressurizable chamber **2610**, a rock sample **2680**, one or more acoustic sensors **2570**, a cover **2630**, and the drain pipe **2595**. In some exemplary embodiments, the acoustic emission testing device **2605** also includes one or more couplings **2594** and the drain pipe pressure control valve **2597**. Although the rock sample **2680** is depicted in the exemplary embodiment, other types of porous samples can be

used in lieu of the rock sample 2680 according to other alternative exemplary embodiments. Since the analog-to-digital converter 2592, the data recorder 2590, the acoustic sensors 2570, the drain pipe 2595, the couplings 2594, and the drain pipe pressure control valve 2597 have been previously described in detail with respect to FIG. 25, these components are not described in detail again with respect to FIG. 26.

The pressurizable chamber 2610 is cylindrically shaped and forms a cavity 2612 therein. However, according to other exemplary embodiments, the pressurizable chamber 2610 is shaped in some other geometric shape, such as a cube-shape, or non-geometric shape. The pressure within the pressurizable chamber 2610 is variable in a controllable and measurable manner. The pressure within the pressurizable chamber 2610 is variable from zero psi to about 40000 psi in some exemplary embodiments; however, the range of pressures can be higher or lower in other exemplary embodiments. The pressurizable chamber 2610 includes a base 2614 and a sidewall 2616 extending substantially perpendicular around the perimeter of the base 2614. In some alternative exemplary embodiments, the sidewall 2616 extends substantially perpendicular from the base 2614 at a position that is within the perimeter of the base 2614. According to some exemplary embodiments, the top portion of the sidewall 2616 includes threads 2617 for receiving and coupling with the cover 2630. However, in other exemplary embodiments, the cover 2630 is sealably coupled to the top portion of the sidewall 2616 using other methods known to people having ordinary skill in the art, such as using fasteners and using welds. The pressurizable chamber 2610 is fabricated from steel; however, according to other exemplary embodiments, the pressurizable chamber 2610 is fabricated from any metal, metal alloy, polymer, wood, or other suitable material known to people having ordinary skill in the art that is capable of withstanding at least a second pressure ( $P_0$ ) 2627, which is described in further detail below. In certain exemplary embodiments, the suitable material is capable of being machined or molded and is capable of propagating sound. In certain exemplary embodiments, the suitable material is capable of propagating sound at a speed of about 1 kilometers per second or higher.

The cavity 2612 is formed within the pressurizable chamber 2610 and is sized to receive the entire rock sample 2680, or some other hard or superhard material. The cavity 2612 is sized larger in diameter than the diameter of the rock sample 2680, thereby allowing the rock sample 2680 to easily and freely fit within the cavity 2612. The cavity 2612 is circular in shape, but is any other geometric or non-geometric shape in other exemplary embodiments. The cavity 2612 is formed by machining the pressurizable chamber 2610 or molding the pressurizable chamber 2610 to have the cavity 2612 formed therein. Alternatively, the cavity 2612 is formed using other methods known to people having ordinary skill in the art. In certain exemplary embodiments, the cavity 2612 is formed in a manner to ensure that the rock sample 2680 is properly aligned in the same manner each time the rock sample 2680 is inserted within the cavity 2612. For example, the base 2614 can be keyed to receive the rock sample 2680 in a desired position. For example, the base 2614 includes one or more protrusions and/or one or more indentations in certain exemplary embodiments.

The rock sample 2680 is a porous material. According to some exemplary embodiments, the rock sample 2680 is formed from a sample of rock obtained from within a drill hole, or wellbore, located at some depth within the wellbore and at a confining pressure. Some examples of rock samples 2680 include, but are not limited to, coal, chalk, shale, limestone, sandstone, all geological formations that include gas or

oil, and other known porous rocks. The rock sample 2680 is substantially cylindrical in shape, but can be shaped into other geometric shapes, such as substantially cube-shaped, or non-geometric shapes. The rock sample 2680 includes a top surface 2682, a bottom surface 2684, and a sidewall 2686 extending from the top surface 2682 to the bottom surface 2684. The top surface 2682 and the bottom surface 2684 are substantially parallel to one another; however, according to other exemplary embodiments, the top surface 2682 and the bottom surface 2684 are not parallel to one another. The sidewall 2686 extends substantially perpendicular to both the top surface 2682 and the bottom surface 2684; however, in certain exemplary embodiments, the sidewall 2686 is not perpendicular to at least one of the top surface 2682 and the bottom surface 2684. According to some exemplary embodiments, the sidewall 2686 is arcuate; however, according to some other exemplary embodiments, at least some portions of the sidewall 2686 includes one or more planar surfaces (not shown). In these exemplary embodiments, these planar surfaces facilitate acoustic sensors 2570 being coupled to the rock sample 2680.

The rock sample 2680 also includes an opening 2681 extending from the top surface 2682 to the bottom surface 2684. The opening 2681 is positioned centrally through the rock sample 2680; however, in other exemplary embodiments, the opening 2681 can be positioned off-centered through the rock sample 2680. In alternative exemplary embodiments, the opening 2681 extends toward the bottom surface 2684 but does not extend through the bottom surface 2684. The rock sample 2680 is inserted within the cavity 2612 so that the bottom surface 2684 is adjacent to the base 2614. According to some exemplary embodiments, the rock sample 2680 is positioned substantially in the center of the cavity 2612; however, the rock sample 2680 can be positioned off-center of the cavity 2612 in other exemplary embodiments.

The acoustic sensor 2570 has been previously described and will not be described in detail for the sake of brevity. One or more acoustic sensors are positioned along the sidewall 2686 of the rock sample 2680. According to some exemplary embodiments, the one or more acoustic sensors 2570 are positioned along the exterior portion of the sidewall 2616 of the pressurizable chamber 2610. The acoustic sensor 2570 detects elastic wave signals formed in the rock sample 2680, which then converts the elastic waves signal to a voltage signal so that the data can be recorded and subsequently analyzed.

The acoustic sensor 2570 is communicably coupled to the data recorder 2590, via the analog-to-digital converter 2592 in certain exemplary embodiments, so that the voltage signal derived from the elastic waves occurring within the rock sample 2680 can be stored and subsequently analyzed. The data recorder 2590 and the analog-to-digital converter 2592, along with their respective set-ups, have been previously described and will not be described in detail for the sake of brevity. In the example where the acoustic sensor 2570 is placed on the rock sample 2680, the first cable 2591 is routed from within the pressurizable chamber 2610 to an area outside the pressurizable chamber 2610 through the coupling 2594, which also has been previously described above and therefore will not be repeated for the sake of brevity.

According to the exemplary embodiment illustrated in FIG. 26, there are three acoustic sensors 2570 shown to be coupled to the rock sample 2680. However, the number of acoustic sensors 2570 ranges from one acoustic sensor 2570 to any number of acoustic sensors 2570. The acoustic sensors 2570 is able to detect the intensity of acoustic events occurring on or within the rock sample 2680 with respect to time

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and space. Thus, the location of the acoustic events and the direction in which the cracks are propagating within the rock sample 2680 are determinable. According to some examples, at least one or more acoustic sensors 2570 are positioned at different elevational heights along the sidewall 2686. In one example, three acoustic sensors 2570 are coupled to the rock sample 2680 at different elevational heights along the sidewall 2586. A first acoustic sensor 2570 detects the intensity of the acoustic event occurring within the rock sample 2680 at a first time period and determines the location of the acoustic event occurring within the rock sample 2680 along a first axis, or x-axis. A second acoustic sensor 2570 detects the intensity of the acoustic event occurring within the rock sample 2680 at the first time period and determines the location of the acoustic event occurring within the rock sample 2680 along a second axis, or y-axis. A third acoustic sensor 2570 detects the intensity of the acoustic event occurring within the rock sample 2680 at the first time period and determines the location of the acoustic event occurring within the rock sample 2680 along a third axis, or z-axis. The acoustic sensors 2570 perform the same analysis at a second time period, a third time period, and so forth. Using the speed of sound known within the rock sample 2680, data from the three acoustic sensors 2570 provide information for determining the intensity of the acoustic event occurring within the rock sample 2680, the location of the acoustic event occurring within the rock sample 2680, and the direction in which the acoustic event is propagating within the rock sample 2680. In the embodiments where the acoustic sensors 2570 are positioned along the pressurizable chamber's sidewall 2616, the speed of sound through a first fluid 2621 and the distance between the respective acoustic sensor 2570 and the rock sample's sidewall 2686 also are used in the determinations. If fewer acoustic sensors 2570 are used, one or more axes are lost for determining where the acoustic event is occurring within the rock sample 2680 along those axes. Each acoustic sensor 2570 represents an axis. When greater than three acoustic sensors 2570 are used, the measurements provide more precise determinations for locating the acoustic events occurring within the rock sample 2680. The data from the three acoustic sensors 2570 are used to triangulate the location of the acoustic events.

The cover 2630 is substantially disc-shaped and includes a bottom surface 2634, a top surface 2636, and a sidewall 2638 extending from the perimeter of the base 2634 to the top surface 2636. According to some exemplary embodiments, the sidewall 2638 is planar, while in other exemplary embodiments, the sidewall 2638 is non-planar. The bottom surface 2634 is configured to be inserted within the top portion of the pressurizable chamber's sidewall 2616 and form a seal therewith. The top surface 2636 is dimensioned the same as the bottom surface 2634 according to some exemplary embodiments, while in other exemplary embodiments, the top surface 2636 is dimensioned larger or smaller than the bottom surface 2634. According to some exemplary embodiments, at least the bottom portion of the sidewall 2638 includes mating threads 2639 for mating with the threads 2617. In other exemplary embodiments, the entire sidewall 2638 includes mating threads 2639. Although mating threads 2639 are used in some exemplary embodiments to sealably couple the top portion of the sidewall 2616 to the cover 2630, other methods known to people having ordinary skill in the art can be used, such as using fasteners and using welds. The cover 2630 is fabricated from steel; however, according to other exemplary embodiments, the cover 2630 is fabricated from any metal, metal alloy, polymer, wood, or other suitable material known to people having ordinary skill in the art that is capable of

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withstanding at least the second pressure ( $P_0$ ) 2627, which is described in further detail below.

The cover 2630 also includes an opening 2632 extending therethrough. The opening 2632 is substantially positioned centrally within the cover 2630 and is sized to be the same diameter or shape as the opening 2681. However, opening 2632 can be sized and/or shaped differently than opening 2681 according to other exemplary embodiments. According to the exemplary embodiment, at least a portion of the opening 2632 is vertically aligned with at least a portion of the opening 2681.

A first seal 2631 is positioned about the perimeter of the opening 2632 and provides a pressure seal between the cover 2630 and the rock sample 2680 about the opening 2632 and the opening 2681, thereby preventing or minimizing any second fluid 2626 leakage from the interface between the opening 2681 and the opening 2632. The first seal 2631 is shaped similar to the shape of the opening 2632. A second seal 2633 is positioned at a location on the bottom surface 2634 which contacts the top surface 2682 of the rock sample 2680. In some exemplary embodiments, the second seal 2633 is positioned at a location on the bottom surface 2634 which contacts the perimeter of the top surface 2682 of the rock sample 2680. The second seal 2633 provides a pressure seal between the cover 2630 and the rock sample 2680 substantially about the perimeter of the top surface 2682 of the rock sample 2680, thereby preventing or minimizing any first fluid 2621 leakage from the interface between the cover 2630 and the perimeter of the top surface 2682 of the rock sample 2680. A third seal 2635 is positioned at the perimeter of the bottom surface 2634 of the cover 2630. The third seal 2635 provides a pressure seal between the cover 2630 and the sidewall 2616 of the pressurizable chamber 2610, thereby preventing or minimizing any first fluid 2621 leakage from the interface between the cover 2630 and the sidewall 2616 of the pressurizable chamber 2610. The seals 2631, 2633, and 2635 are a rubber gasket or any other suitable material known to people having ordinary skill in the art. Once the bottom portion of the cover 2630 is properly inserted into the pressurizable chamber 2610, the first seal 2631 and the second seal 2633 are in contact with the top surface 2682 of the rock sample 2680. The pressure within the cavity 2612 surrounding the rock sample 2680 is a first pressure ( $P_1$ ) 2622 which can be different than the second pressure 2627 within the openings 2632 and 2681 during testing which is described in further detail below. Each of the first pressure 2622 and the second pressure 2627 is variable. Thus, a portion of the rock sample 2680 is exposed to the first pressure 2622 while another portion of the rock sample 2680 is exposed to the second pressure 2627 during testing.

Within the cavity 2612 surrounding the rock sample 2680, a first fluid 2621 is placed. This portion of the cavity 2612 can be referred to as a first chamber 2620. The first fluid 2621 fills up the first chamber 2620 in some exemplary embodiments; however, in other exemplary embodiments, the first fluid 2621 fills a portion of the first chamber 2620. The first fluid 2621 is water. However, other types of fluid having similar properties can be used as the first fluid 2621 in other exemplary embodiments. In some exemplary embodiments, the first fluid 2621 includes sand particles or other similar particle types.

A second fluid 2626 flows into and fills up the opening 2681. According to some exemplary embodiments, the second fluid 2626 is pumped into opening 2632 and opening 2681. However, in other exemplary embodiments, the pressure of the second fluid is provided using other known methods, such as having a reservoir of second fluid fluidly coupled to the openings 2632 and 2681 and having a piston (not

shown) provide a force to a movable plate (not shown) within the reservoir, similar to the second barrier 2540 described above. The opening 2681 can be referred to as a second chamber. The second fluid 2626 is water. However, other types of fluid having similar properties can be used as the second fluid 2626 in other exemplary embodiments. In some exemplary embodiments, the second fluid 2626 includes sand particles or other similar particles.

As the second pressure 2627 increases and the second fluid 2626 flows into the first chamber 2620 through the rock sample 2680, the first pressure 2622 increases. To maintain the first pressure 2622 constant or substantially constant, a drain pipe 2595 is coupled to the interior of the first chamber 2620 and through the sidewall 2616 to allow the first fluid 2621 and/or the second fluid 2626 that is present within the first chamber 2620 to exit the first chamber 2620. The drain pipe 2595 is fabricated from a metal, metal alloy, polymer, or other suitable material capable of withstanding the first pressure 2622. In certain exemplary embodiments, the drain pipe pressure control valve 2597 is installed at a location along the drain pipe 2595 and is configured to be opened and closed, either automatically or manually, to maintain the first pressure 2622 at a substantially constant pressure during the testing process. In alternative exemplary embodiments, the drain pipe 2595 is coupled to the interior of the first chamber 2620 through the base 2614.

The operation of the acoustic emission testing system 2600 is described while referring to FIG. 26. Once the acoustic emission testing system 2600 is configured according to the description provided above, the drain pipe control valve 2597 is set to maintain the pressure in the first chamber 2620 at the first pressure 2622. The first pressure 2622 is determined to be the rock confining pressure, which is the pressure at which the rock sample 2680 was exposed to while in the wellbore. The second fluid 2626 is pushed into the second chamber 2681 at the second pressure 2627 which applies a force on the rock sample 2680 from within. The second pressure 2627 increases to a value above the first pressure 2622 and is ramped up so that acoustic events, or cracking, occurs on or within the rock sample 2680. The second pressure 2627 is continuously ramped up until the second pressure 2627 reaches a threshold pressure, where extensive acoustic events occur within the rock sample 2680. Once the second pressure 2627 increases above the first pressure 2622, the second fluid 2626 passes through the porous rock sample 2680 and enters into the first chamber 2620. The first pressure 2622 would typically increase due to the second fluid 2626 entering the first chamber 2620; however, the drain pipe control valve 2597 maintains the first pressure 2622 substantially constant and allows the first fluid 2621 and/or the second fluid 2626 that has entered into the first chamber 2620 to exit the first chamber 2620 through the pipe drain 2595. This threshold pressure that is reached is the pressure that is to be generated in the wellbore for fracing the rock at that confining pressure. During the testing procedure, the acoustic events are measured according to the descriptions provided above. Additionally, the location of the acoustic events are determinable by people having ordinary skill in the art having the benefit of the present disclosure. Moreover, the direction in which the acoustic events are propagating also are determinable by people having ordinary skill in the art having the benefit of the present disclosure. The acoustic sensors 2570 obtain data when the second pressure 2627 is increased. Additionally, in some exemplary embodiments, the acoustic sensors 2570 also obtain data when the second pressure 2627 is decreased after reaching the threshold pressure. Although not illustrated, the first pressure 2622 and the second pressure 2627

are monitored. According to some exemplary embodiments, the second pressure 2627 is recorded.

FIG. 27 shows an acoustic testing method 2700 in accordance with an exemplary embodiment. Although the acoustic testing method 2700 illustrates one or more steps occurring in a certain order, one or more of the steps occur in a different order according to other exemplary embodiments. Additionally, one or more steps are combined into fewer steps according to some exemplary embodiments, while one or more steps are expanded into more steps according to some exemplary embodiments. Thus, the illustrated order of steps and the number of steps are not to be construed as being limiting.

The acoustic testing method 2700 includes a step 2710. At step 2710, a rock sample is obtained from a wellbore at a certain depth and a rock confining pressure exposed on the rock sample within the wellbore is observed. According to some exemplary embodiments, the rock sample is obtained from the wellbore that is currently being drilled. In other exemplary embodiments, the rock sample is obtained from a wellbore that is nearby a site that is intended to be drilled. The method 2700 also includes step 2715 where the rock sample is prepared so that the rock sample is insertable within a pressurizable chamber. The rock sample is fabricated into a desired shape so that it is insertable within the pressurizable chamber. Once the rock sample is prepared, the method proceeds to step 2720 where the prepared rock sample is properly placed in the pressurizable chamber such that a first portion of the rock sample is exposable to a first chamber at a first pressure and a second portion of the rock sample is exposable to a second chamber at a second pressure. According to some exemplary embodiments, the first portion includes at least a portion of the sidewall of the rock sample and the second portion includes the top surface of the rock sample. According to some other exemplary embodiments, the first portion includes the top surface of the rock sample and the second portion includes at least a portion of the sidewall of the rock sample. Yet, according to some other exemplary embodiments, the first portion includes an exterior portion of the rock sample, such as the outer surface of the sidewall, and the second portion includes an interior portion of the rock sample. In an alternative exemplary embodiment, the first portion includes an interior portion of the rock sample and the second portion includes an exterior portion of the rock sample, such as the outer surface of the sidewall.

The method 2700 also includes step 2725, where one or more acoustic sensors are communicably coupled to the rock sample. According to some exemplary embodiments, three acoustic sensors are coupled to the surface of the rock sample in a manner where each acoustic sensor is positioned at a different elevation from one another. Although three acoustic sensors are coupled to the rock sample, greater or fewer acoustic sensors are usable in other exemplary embodiments. Also, although each acoustic sensor is positioned at a different elevation from one another, at least one acoustic sensor is positionable substantially at the same elevation as another acoustic sensor in other exemplary embodiments. Further, although the acoustic sensors are coupled to the surface of the rock sample, one or more of the acoustic sensors are coupled to the pressurizable chamber in other exemplary embodiments.

The method 2700 also includes step 2730, where the first pressure in the first chamber is pressurized to at or substantially at the rock confining pressure, which is the pressure that the rock sample was exposed to while in the wellbore. According to some exemplary embodiments, a first fluid that has been placed in the first chamber exerts the first pressure onto the first portion of the rock sample. The method 2700

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also includes step 2735, where the second pressure in the second chamber is increased to a threshold pressure while the acoustic events occurring within the rock sample are recorded over time and space. According to some exemplary embodiments, a second fluid, which is the same or similar to the first fluid, has been placed in the second chamber and exerts the second pressure onto the second portion of the rock sample. The threshold pressure is the pressure at which acoustic events are formed quickly and extensively within and/or on the rock sample.

The method 2700 also includes step 2740. In step 2740, the fracturing events that occurred over time and space are analyzed. This analysis includes the processes described above according to some exemplary embodiments. According to some exemplary embodiments, the intensity of one or more fracturing events, or acoustic events, is determined. According to some exemplary embodiments, the location of one or more fracturing events, or acoustic events, that occurred within the rock sample is determined. According to some exemplary embodiments, the direction in which one or more fracturing events, or acoustic events, are propagating is determined. After step 2740, the method 2700 proceeds to step 2745. In step 2745, at least one parameter of a high pressure down hole fracturing program or at least one parameter of a down hole drilling program targeted to the sampled formation is determined based upon the analysis of the fracturing events. For example, based upon the analysis, the pressure that needs to be exerted by the bit on the rock within the wellbore to create a proper fracturing program is the threshold pressure, which is the pressure of the second pressure when substantial fracturing of the rock occurs. In another example, the weight-on-bit is calculable from knowing the pressure that the bit is to exert on the rock within the wellbore.

FIG. 28 shows a cross-sectional view of an acoustic emission testing system 2800 in accordance with yet another exemplary embodiment of the present invention. Referring to FIG. 28, the acoustic emission testing system 2800 includes an acoustic emission testing device 2805 communicably coupled to a data recorder 2809. The acoustic emission testing device 2805 includes a cutter holder 2810, the cutter 100, the indenter 550, an acoustic sensor holder 2850, an acoustic sensor 2870, a first rod 2890, and a second rod 2895. Although the cutter 100 is depicted in the exemplary embodiment, the rock sample 2300 (FIG. 23) or other type of hard or superhard component, replaces the cutter 100 in alternative exemplary embodiments.

The cutter holder 2810 includes a first surface 2812, a second surface 2814, and a side surface 2816. The first surface 2812 is disposed in a plane that is substantially parallel to the plane that the second surface 2814 is disposed. The side surface 2816 extends from the perimeter of the first surface 2812 to the perimeter of the second surface 2814. According to some exemplary embodiments, the side surface 2816 is substantially perpendicular to at least one of the first surface 2812 and the second surface 2814. According to alternative exemplary embodiments, the side surface 2816 is not substantially perpendicular to either the first surface 2812 or the second surface 2814. The cutter holder 2810 is shaped in a substantially cylindrical shape, wherein the first surface 2812 is substantially circular shaped, the second surface 2814 is substantially circular shaped, and the side surface 2816 is substantially cylindrically and arcuately shaped. Although one exemplary shape is provided for the cutter holder 2810, the cutter holder 2810 can be shaped into any other geometric or non-geometric shape, such as a square shaped cylinder or a triangular shaped cylinder, without departing from the scope and spirit of the exemplary embodiment. The cutter

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holder 2810 is fabricated from steel; however, according to other exemplary embodiments, the cutter holder 2810 is fabricated from any metal, wood, or other suitable material known to people having ordinary skill in the art that is capable of withstanding a load 2880, which is described in further detail below. The load 2880 ranges from about zero kilonewtons to about seventy kilonewtons, but is higher in other exemplary embodiments. In certain exemplary embodiments, the suitable material is capable of being machined or molded and is capable of propagating sound therethrough. In certain exemplary embodiments, the suitable material is capable of propagating sound at a speed of about 1 kilometers per second or higher.

The cutter holder 2810 also includes a first cavity 2820 and a second cavity 2830 according to some exemplary embodiments. In certain exemplary embodiments, the cutter holder 2810 also includes a channel 2838 extending from the first cavity 2820 to the second cavity 2830. The first cavity 2820 is formed within the first surface 2812 of the cutter holder 2810 and extends toward the second surface 2814, but does not reach the second surface 2814. The first cavity 2820 includes a first portion 2821 and a second portion 2825 formed adjacent to the first portion 2821 according to certain exemplary embodiments. The first portion 2821 extends from the first surface 2812 of the cutter holder 2810 and extends into the cutter holder 2810 to the second portion 2825. According to some exemplary embodiments, the first portion 2821 is formed having a circular cross-section; however, the shape is different in other exemplary embodiments. The first portion 2821 is sized to receive at least a portion of the indenter 550, which has previously been described. For example, the first portion 2821 is sized slightly larger in diameter than the diameter of the indenter 550, thereby allowing the indenter 550 to easily and freely fit within the first portion 2821.

The second portion 2825 extends from the first portion 2821 towards the second surface 2814. According to some exemplary embodiments, the second portion 2825 is formed having a circular cross-section; however, the shape is different in other exemplary embodiments. The second portion 2825 is sized to receive at least a portion of the cutter 100, which has previously been described, or some other hard or superhard material, such as the rock sample 2300 (FIG. 23), for which properties are to be determined. For example, the diameter of the second portion 2825 is sized slightly larger in diameter than the diameter of the cutter 100, thereby allowing the cutter 100 to easily and freely fit within the second portion 2825. According to some exemplary embodiments, the central axial axis of the first portion 2821 is substantially the same as the central axial axis of the second portion 2825; however, these axes are aligned differently in other exemplary embodiments. In some exemplary embodiments, the second portion 2825 has a smaller diameter than the first portion 2821. In certain exemplary embodiments, the first cavity 2820 includes the second portion 2825, but not the first portion 2821. Thus, in these exemplary embodiments, the second portion 2825 extends from the first surface 2812 towards the second surface 2814.

In certain exemplary embodiments, the second cavity 2830 is formed within the second surface 2814 of the cutter holder 2810 and extends toward the second portion 2825 of the first cavity 2820, but does not reach the second portion 2825. However, this second cavity 2830 is optional. A thickness 2835 is formed between the second portion 2825 and the second cavity 2830. The thickness 2835 is able to withstand the load 2880 without breaking. According to some exemplary embodiments, the second cavity 2830 is formed having a conical cross-section; however, the shape is different in

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other exemplary embodiments. The second cavity **2830** is sized to receive at least a portion of the acoustic sensor **2870**, which is described in further detail below. In exemplary embodiments that do not include the second cavity **2830**, the acoustic sensor **2870** is positioned adjacent to the second surface **2814**.

According to some exemplary embodiments, the channel **2838** is formed extending from the second cavity **2830** to the second portion **2825** of the first cavity **2820**. The central axial axis of the channel **2838** corresponds to the previously mentioned central axial axes according to certain exemplary embodiments. The channel **2838** provides a direct pathway for the acoustic waves to travel from the cutter **100** to the acoustic sensor **2870**.

One or more of the cavities **2820**, **2830**, and channel **2838** are formed by machining the cutter holder **2810** or molding the cutter holder **2810** to have the cavities **2820**, **2830** and the channel **2838** formed therein. Alternatively, one or more of the cavities **2820**, **2830** and the channel **2838** are formed using other methods or combination of methods known to people having ordinary skill in the art. In certain exemplary embodiments, the first cavity **2820** is formed in a manner to ensure that the cutter **100** is properly aligned in the same manner each time the cutter **100** is inserted within the first cavity **2820**.

The cutter **100** has been previously described and is applicable to the exemplary embodiments. Briefly, the cutter **100** includes the substrate **110** and the cutter table **120**, which is formed or coupled to the top of the substrate **110**. In the exemplary embodiment, the cutter table **120** is formed from PCD, but alternative exemplary embodiments have the cutter table **120** fabricated from other materials, such as PCBN, without departing from the scope and spirit of the exemplary embodiment. Although cutter **100** has a planar cutter table **120**, or is flat-faced, the cutter table **120** can be dome shaped, concave shaped, or any other shape known to people having ordinary skill in the art. As previously mentioned, the cutter **100** includes finished and/or grounded cutters as well as “raw” cutters.

The cutter **100** is inserted within the second portion **2825** of the first cavity **2820**. The cutter **100** is oriented within the second portion **2825** so that the cutter table **120** is facing towards the first surface **2812**, or away from the second surface **2814**. According to some exemplary embodiments, the entire cutter **100** is inserted within the second portion **2825**. However, in alternative exemplary embodiments, a portion of the cutter **100**, which includes substantially the entire substrate **110**, is inserted within the second portion **2825** of the first cavity **2820**. Thus, in these alternative exemplary embodiments, at least a portion of the cutter table **120** is not inserted within the second portion **2825**. The portion of the cutter **100** inserted within the second portion **2825** is securely positioned therein. However, according to some exemplary embodiments, the portion of the cutter **100** inserted within the second portion **2825** is loosely positioned therein. According to these other exemplary embodiments, a lubricant (not shown) is disposed within the second portion **2825** between the cutter **100** and the surface of the second portion **2825**. Although the cutter **100** is described as being used in this exemplary embodiment, other hard or superhard materials that desire a toughness testing can be used in lieu of the cutter **100**.

The indenter **550** has been previously described and is not repeated for the sake of brevity. The indenter **550** is sized to fit within at least the first portion **2821** of the first cavity **2820** so that it makes contact with the cutter **100**. In certain exemplary embodiments, the perimeter of the indenter **550** is sized sub-

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stantially similar to the perimeter of the first portion **2821**. However, in the exemplary embodiments where at least a portion of the cutter table **120** is not within the first cavity **2820** and is positioned elevationally above the first surface **2812**, the indenter **550** can be dimensioned such that the perimeter of the indenter **550** is greater than the perimeter of the first portion **2821** of the first cavity **2820**. The indenter **550** is oriented so that the indenter's first end **650** makes contact with the cutter **100**. Thus, in this embodiment, indenter **550** makes contact with the PDC layer, or cutter table **120**, of the cutter **100**. The load **2880** is applied to the indenter's second end **652**, which transmits the load **2880** onto the cutter **100**.

The acoustic sensor holder **2850** includes a first surface **2852**, a second surface **2854**, and a side surface **2856**. The first surface **2852** is disposed in a plane that is substantially parallel to the plane that the second surface **2854** is disposed. The side surface **2856** extends from the perimeter of the first surface **2852** to the perimeter of the second surface **2854**. According to some exemplary embodiments, the side surface **2856** is substantially perpendicular to at least one of the first surface **2852** and the second surface **2854**. According to alternative exemplary embodiments, the side surface **2856** is not substantially perpendicular to either the first surface **2852** or the second surface **2854**. The acoustic sensor holder **2850** is shaped in a substantially cylindrical shape, wherein the first surface **2852** is substantially circular shaped, the second surface **2854** is substantially circular shaped, and the side surface **2856** is substantially cylindrically and arcuately shaped. Although one exemplary shape is provided for the acoustic sensor holder **2850**, the acoustic sensor holder **2850** is shaped differently in other exemplary embodiments. The acoustic sensor holder **2850** is fabricated from cemented carbide, such as cemented tungsten carbide; however, according to other exemplary embodiments, the acoustic sensor holder **2850** is fabricated from any other suitable material, such as lead, that has an acoustic impedance that is higher than the material used to fabricate the second rod **2895** and that is capable of withstanding the load **2880**. In certain exemplary embodiments, the suitable material is capable of being machined or molded and is capable of propagating sound. In certain exemplary embodiments, the suitable material is capable of propagating sound at a speed of about 1 kilometers per second or higher. The material that the acoustic sensor holder **2850** is fabricated has a higher acoustic impedance than the material used to fabricate the second rod **2895**, which thereby causes the noise sound waves to be reflected into the second rod **2895** and not back into the acoustic sensor **2870**. Hence, the signal to noise ratio that is detected by the acoustic sensor **2870** is improved within the system **2800**.

The acoustic sensor holder **2850** also includes a first cavity **2860** and a second cavity **2868** according to some exemplary embodiments. The first cavity **2860** is formed within the first surface **2852** of the acoustic sensor holder **2850** and extends toward the second surface **2854**, but does not reach the second surface **2854**. The first cavity **2860** includes a first portion **2861** and a second portion **2863** formed adjacent to the first portion **2861** according to certain exemplary embodiments. The first portion **2861** extends from the first surface **2852** of the acoustic sensor holder **2850** to the second portion **2863** within the acoustic sensor holder **2850**. According to some exemplary embodiments, the first portion **2861** is formed having a circular cross-section; however, the shape is different in other exemplary embodiments. The first portion **2861** is sized to securely receive a lower portion of the cutter holder **2810**, which includes the cutter holder's second surface **2814**. For example, the first portion **2861** is sized slightly larger in diameter than the diameter of the cutter holder's second sur-



face **2814**, thereby allowing the cutter holder's second surface **2814** to easily and securely fit within the first portion **2861**.

The second portion **2863** extends from the first portion **2861** towards the second surface **2854**. According to some exemplary embodiments, the second portion **2863** is formed having a circular cross-section; however, the shape is different in other exemplary embodiments. The second portion **2863** is sized to receive at least a portion of the acoustic sensor **2870**. For example, the diameter of the second portion **2863** is sized larger than the diameter of the acoustic sensor **2870**. According to some exemplary embodiments, the central axial axis of the first portion **2861** is substantially the same as the central axial axis of the second portion **2863**; however, these axes are aligned differently in some other exemplary embodiments. In some exemplary embodiments, the second portion **2863** has a smaller diameter than the first portion **2861**.

In certain exemplary embodiments, the second cavity **2868** is formed within the second surface **2854** of the acoustic sensor holder **2850** and extends toward the second portion **2863** of the first cavity **2860**, but does not reach the second portion **2863**. However, this second cavity **2868** is optional. A thickness **2869** is formed between the second portion **2863** and the second cavity **2868**. The thickness **2869** is able to withstand the load **2880** without breaking. According to some exemplary embodiments, the second cavity **2868** is formed having a circular cross-section; however, the shape is different in other exemplary embodiments. The second cavity **2868** is sized to receive at least a portion of the second rod **2895**, which is described in further detail below.

The cavities **2860**, **2868** are formed by machining the acoustic sensor holder **2850** or molding the acoustic sensor holder **2850** to have the cavities **2860**, **2868** formed therein. Alternatively, the cavities **2860**, **2868** are formed using other methods or combination of methods known to people having ordinary skill in the art.

The acoustic sensor **2870** is a piezoelectric sensor in some exemplary embodiments; however, the acoustic sensor **2870** is any other device type known to people having ordinary skill in the art, wherein the device is capable of detecting acoustic transmissions. The acoustic sensor **2870** detects elastic wave signals formed in the cutter **100**, which then converts the elastic waves signal to a voltage signal so that the data can be recorded and subsequently analyzed. The acoustic sensor **2870** has a sensitivity range spanning from one to about 1,000 kilohertz, which allows the detection of acoustic emission events too weak or too short to be detected based upon previously described system configurations. The acoustic sensor **2870** is positioned within at least the second portion **2863** of the acoustic sensor holder's first cavity **2860**. In certain exemplary embodiments, a portion of the acoustic sensor **2870** extends into the first portion **2861** of the acoustic sensor holder's first cavity **2860**. The acoustic sensor **2870** is coupled to or is in contact with the cutter holder **2850**. In certain exemplary embodiments, a portion of the acoustic sensor **2870** is received within the second cavity **2830** of the cutter holder **2810**. In some exemplary embodiments, each of the indenter **550**, the cutter **100**, and the acoustic sensor **2870** are substantially aligned linearly. In certain exemplary embodiments, a low density material **2875**, such as a lubricant, is placed around the acoustic sensor **2870** once positioned within the acoustic sensor holder's first cavity **2860**. The low density material **2875** fills in the remaining portion of the first cavity **2860** between at least the surface of the first cavity's second portion **2863** and the acoustic sensor **2870**. The low density material **2875** isolates the acoustic sensor **2870** from detecting surrounding environmental noise or at

least reduces the detection of this noise. The acoustic sensor **2870** is communicably coupled to the data recorder **2809** so that the voltage signal derived from the elastic waves occurring within the cutter **100** can be stored and subsequently analyzed. The acoustic sensor **2870** is coupled to the data recorder **2809** using a cable **2808**; however, according to other exemplary embodiments, the acoustic sensor **2870** is communicably coupled to the data recorder **2809** wirelessly using wireless technology including, but not limited to, infrared and radio frequency. In the embodiments where the cable **2808** couples the acoustic sensor **2870** to the data recorder **2809**, a passageway **2851** is formed extending from the acoustic sensor holder's side surface **2856** to the acoustic sensor holder's first cavity **2860**. The passageway **2851** allows the cable **2808** to communicate from within the acoustic sensor holder's first cavity **2860** to the data recorder **2809**.

The first rod **2890** includes a first end **2891** that is oriented to apply the load **2880** onto the indenter's second end **652**.

The second rod **2895** includes a first end **2896** that is shaped to be securely coupled to the lower portion of the acoustic sensor holder **2850**. The first end **2896** includes a raised portion **2897** and a recessed portion **2898** surrounding the raised portion **2897**. The raised portion **2897** is shaped similarly to the shape of the acoustic sensor holder's second cavity **2868** so that at least a portion of the raised portion **2897** is insertable into the acoustic sensor holder's second cavity **2868** to securely couple the second rod **2895** to the acoustic sensor holder **2850**. The raised portion **2897** includes a substantially planar surface **2899** according to some exemplary embodiments; however, the surface **2899** is non-planar depending upon the shape of the acoustic sensor holder's second cavity **2868** in other exemplary embodiments. The second rod **2895** is fabricated using steel, or alternatively, any other suitable material capable of withstanding the load **2880** and having a lower acoustic impedance than the material used to fabricate the acoustic sensor holder **2850**, such as aluminum, brass, plastic, and wood. As previously mentioned, this low acoustic impedance material allows the sound to continue travelling into and through the material, rather than being reflected back into the acoustic sensor **2870**. In certain exemplary embodiments, at least one of the cutter holder **2810**, the acoustic sensor holder **2850**, and the second rod **2895** is fabricated from a material having a much higher density or a much lower density than at least one of the other remaining components. For example, the density of one of the components is at least about 1.5 times greater than at least one of the previously mentioned components.

Although one exemplary configuration of the acoustic emission testing device **2805** has been illustrated and described, other configurations, known to people having ordinary skill in the art having the benefit of the present disclosure, can be used without departing from the scope and spirit of the exemplary embodiments. For example, the coupling and/or interlocking features of adjacent components can be performed in a variety of ways in other exemplary embodiments. For example, the lower portion of the cutter holder **2810** is partially inserted within a first cavity **2860** formed in the upper portion of the acoustic sensor holder **2850**. Alternatively, in other exemplary embodiments, the upper portion of the acoustic sensor holder **2850** is partially inserted within a cavity (not shown) formed in the lower portion of the cutter holder **2810**.

The data recorder **2809** is similar to the data recorder **590** (FIG. 5), but is capable of recording up to about 100,000 data points per second. In alternative exemplary embodiments, the data recorder **2809** records even more data points per second. The data recorder **2809** records the data sent from the acoustic



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sensor **2870** and stores the data therein. In some exemplary embodiments, the data recorder **2890** also is communicably coupled to one or more components, such as the first rod **2890**, to obtain data for quantifying the load **2880**. The data is processed according to the description provided above.

According to certain embodiments of the present invention, the concepts described above are included within an acoustic emission formation sampling tool, which is further described below. The acoustic emission formation sampling tool is placed downhole into a wellbore and includes one or more indenters and one or more acoustic sensors acoustically coupled to the indenters. The indenters are pushed into the adjacent rock formation within the wellbore with a load progressively increasing from a minimum load towards a maximum load, thereby causing cracks to form therein. The minimum load is about zero kilonewtons, while the maximum load is equal to the load that the drive mechanism, described further below, is capable of producing. The cracking of the rock formation produces acoustic transmissions. The acoustic sensor detects these acoustic transmissions and provides a signal which is used to determine one or more rock properties, such as CCS.

FIG. **29** shows a side schematic view of an acoustic emission formation sampling tool **2900** in an operating position **2902** within a wellbore **2908** in accordance with another exemplary embodiment of the present invention. The acoustic emission formation sampling tool **2900** includes a tool body **2910**, one or more indenter guides **2920**, one or more indenters **2930**, and one or more acoustic sensors **2870**. In certain exemplary embodiments; however, the indenter guides **2920** are optional. A rock formation **2906** radially surrounds the wellbore **2908**.

The tool body **2910** is coupled, either directly or indirectly, to a drill string (not shown) according to some exemplary embodiments, while in other exemplary embodiments, the tool body **2910** is suspended into the wellbore **2908** using one or more cables (not shown). The tool body **2910** is cylindrically shaped and includes an outer surface **2912** which faces a borehole wall **2909** once the tool body **2910** is inserted into the wellbore **2908**. The outer surface **2912** forms at least one cavity **2914** therein, which extends inwardly into the tool body **2910**. Although one cavity **2914** is illustrated, there are several cavities **2914** formed within the outer surface **2912** in other exemplary embodiments. According to some examples, there are a plurality of cavities **2914**, such as four cavities **2914**, formed circumferentially and equidistantly apart around the outer surface **2912**; however, one or more cavities **2914** are not formed equidistantly apart in other exemplary embodiments. In other examples, there are a plurality of cavities **2914** formed in vertical alignment along the outer surface **2912**; however, in other examples, the cavities **2914** are formed at different elevations along the outer surface **2912** and also circumferentially around the perimeter of the outer surface **2912**.

Each indenter guide **2920** is positionably aligned with a respective cavity **2914** and is movable between a non-operating position (not shown), or retracted position, and the operating position **2902**, or expanded position. In certain exemplary embodiments, there are several indenter guides **2920** that are positionably aligned with a single cavity **2914**. According to certain exemplary embodiments, the indenter guide **2920** moves in a substantially perpendicular direction with respect to the longitudinal length of the tool body **2910**; however, one or more indenter guides **2920** move non-perpendicularly with respect to the longitudinal length of the tool body **2910**. In the non-operating position, the indenter guide **2920** is positioned away from the borehole wall **2909** when

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the tool body **2910** is inserted into the wellbore **2908**. In some examples, the indenter guide **2920** is positioned entirely within the cavity **2914** when in the non-operating position. Conversely, in the operating position **2902**, at least a portion of the indenter guide **2920** is positioned in engagement with, adjacent to, or near, the borehole wall **2909** when the tool body **2910** is inserted into the wellbore **2908**.

The indenter guide **2920** includes a sidewall **2922** having a proximal end **2923** and a distal end **2924** at an opposing end from the proximal end **2923**. The sidewall **2922** has a circular cross-sectional shape according to some exemplary embodiments; however, the cross-sectional shape of the sidewall **2922** is different in other exemplary embodiments. The sidewall **2922** forms a channel **2925** extending from the distal end **2924** towards the proximal end **2923**. In certain exemplary embodiments, there are several channels **2925** formed within the indenter guide **2920**. In some exemplary embodiments, the indenter guide **2920** also includes a flange **2921** extending outwardly from the distal end **2924**. According to some exemplary embodiments, the flange **2921** forms a portion of the outer surface **2912** of the tool body **2910** when the indenter guide **2920** is in the non-operating position, or retracted position. According to some exemplary embodiments, a second flange (not shown) extends outwardly from the proximal end **2923**, thereby preventing the indenter guide **2920** from inadvertently being decoupled from the tool body **2910**. For example, the second flange stops the indenter guide **2920** from continuing to move outwardly from the tool body **2910** once the indenter guide **2920** is fully extended. Although a second flange is used in some exemplary embodiments to prevent the indenter guide **2920** from being decoupled from the tool body **2910**, other methods and devices known to persons having ordinary skill in the art and having the benefit of the present disclosure, such as a retaining ring, can be used to accomplish the same purpose without departing from the scope and spirit of the exemplary embodiments.

In certain exemplary embodiments utilizing more than one indenter guide **2920**, one or more of the indenter guides **2920** provide stability to the tool body **2910** when extended into the operating position **2902**. For example, in the exemplary embodiments using two indenter guides **2920** being separated 180 degrees apart, each of the indenter guides **2920** is braced against opposing surfaces of the borehole wall **2909** when both indenter guides **2920** are in the operating position **2902**, which thereby maintains the tool body **2910** substantially along the center axis **2904** of the wellbore **2908**. Although one indenter guide **2920** is illustrated, there are several indenter guides **2920** positioned along the outer surface **2912** of the tool body **2910** in other exemplary embodiments. According to some examples, there are a plurality of indenter guides **2920**, such as four indenter guides **2920**, positioned circumferentially and equidistantly apart around the outer surface **2912**; however, one or more indenter guides **2920** are not positioned equidistantly apart from another indenter guide in other exemplary embodiments. In other examples, there are a plurality of indenter guides **2920** positioned in vertical alignment along the outer surface **2912**; however, in other examples, the indenter guides **2920** are positioned at different elevations along the outer surface **2912** and also circumferentially around the perimeter of the outer surface **2912**.

The indenter guide **2920** is positioned from the non-operating position to the operating position **2902** and back to the non-operating position using a drive mechanism (not shown). The drive mechanism used for moving the indenter guide **2920** is within the purview of persons having ordinary skill in the art and having the benefit of the present disclosure. For example, the drive mechanism is a hydraulic mechanism

according to some exemplary embodiments. However, in alternative exemplary embodiments, the drive mechanism is an electric mechanism, such as a motor, or a pneumatic mechanism. Exemplary drive mechanisms used in performing similar type operations in a downhole tool, which include under reamers, expandable stabilizers, and side wall coring units, are described in U.S. Pat. No. 4,354,558, entitled "Apparatus and Method for Drilling into the Sidewall of a Drill Hole," and issued to Jageler et al. on Oct. 19, 1982; U.S. Pat. No. 4,629,011, entitled "Method and Apparatus for Taking Core Samples from a Subterranean Well Side Wall," and issued to Reinhardt on Dec. 16, 1986; U.S. Pat. No. 4,714,119, entitled "Apparatus for Hard Rock Sidewall Coring a Borehole," and issued to Hebert et al. on Dec. 22, 1987; U.S. Pat. No. 5,617,927, entitled "Sidewall Rotary Coring Tool," and issued to Maissa on Apr. 8, 1997; U.S. Pat. No. 7,493,971, entitled "Concentric Expandable Reamer and Method," and issued to Nevlud et al. on Feb. 24, 2009; and U.S. Pat. No. 7,900,717, entitled "Expandable Reamers for Earth Boring Applications," and issued to Radford et al. on Mar. 8, 2011. Although drive mechanisms used within downhole tools for coring applications and expanding reamer applications are applicable to the present drive mechanism, other drive mechanisms used within other downhole tools may also be applicable as a method or device for moving the indenter guide 2920 without departing from the scope and spirit of the exemplary embodiments.

Each indenter 2930 is positioned within the channel 2925 of a respective indenter guide 2920 and is movable between a non-operating position (not shown) and the operating position 2902 within the indenter guide 2920. Thus, in certain embodiments where several channels 2925 are formed within the indenter guide 2920, a plurality of indenters 2930 are positioned within a single indenter guide 2920. According to certain exemplary embodiments, the indenter 2930 moves in a substantially perpendicular direction with respect to the longitudinal length of the tool body 2910. However, according to other exemplary embodiments, the indenter 2930 moves in a substantially non-perpendicular direction with respect to the longitudinal length of the tool body 2910. In the non-operating position, the indenter 2930 is positioned away from the borehole wall 2909 when the tool body 2910 is inserted into the wellbore 2908. In some examples, the indenter 2930 is positioned entirely within the cavity 2914 when in the non-operating position. Conversely, in the operating position 2902, at least a portion of the indenter 2930 is in engagement with the borehole wall 2909 and is exerting a force onto the borehole wall 2909. Thus, a portion of the indenter 2930 is extendable beyond the distal end 2924 of the indenter guide's sidewall 2922.

The indenter 2930 is similar to indenter 550 (FIG. 5) according to some exemplary embodiments. Indenter 2930 includes a body 2932 and a contact end 2934 coupled to the body 2932. The body 2932 is cylindrically shaped according to some exemplary embodiments, while in other exemplary embodiments, the body 2932 is shaped differently. The body 2932 includes a bottom end 2933 located opposite the contact end 2934. According to some exemplary embodiments, the body 2932 forms a passageway 2931 extending from the bottom end 2933 towards the contact end 2934, which is explained further below. The contact end 2934 is conical-shaped and has a first end 2935 and a second end 2936 positioned opposite the first end 2935. The second end 2936 is coupled to the body 2932. The first end 2935 is substantially planar, but is shaped differently, such as dome-shaped, in other exemplary embodiments. According to some exemplary embodiments, the contact end 2934 is fabricated using

hard or superhard materials, such as polycrystalline diamond compact, and the body 2932 is fabricated using cemented tungsten carbide. However, the contact end 2934 and the body 2932 are fabricated using other known suitable materials, which can be the same material or different materials, that can crack the surrounding rock formation 2906 without itself cracking.

The indenter 2930 is positioned from the non-operating position to the operating position 2902 and back to the non-operating position using a drive mechanism (not shown). The drive mechanism used for moving the indenter 2930 is within the purview of persons having ordinary skill in the art and having the benefit of the present disclosure. The drive mechanism used for moving the indenter 2930 is the same as the drive mechanism used for moving the indenter guide 2920 in some exemplary embodiments. In other exemplary embodiments, the drive mechanism used for moving the indenter 2930 is different than the drive mechanism used for moving the indenter guide 2920. In other exemplary embodiments, the drive mechanism used for moving the indenter 2930 operates in conjunction with the operation of the drive mechanism used for moving the indenter guide 2920.

One or more seal rings 2940 are positioned circumferentially around the body 2932 of the indenter 2930 and provide a seal between the indenter 2930 and the indenter guide 2920. Thus, fluid and/or other contaminants present within the wellbore 2908 do not enter the tool body 2910 through movement of the indenter 2930 and the indenter guide 2920. The seal rings 2940 are fabricated using a suitable material known to persons having ordinary skill in the art, such as an elastomer, a metal, or a metal alloy. A groove (not shown) is present in either of the body 2932 of the indenter 2930 or the sidewall 2922 of the indenter guide 2920. Thus, in some exemplary embodiments, one of either the indenter 2930 or the indenter guide 2920 is stationary with respect to the seal ring 2940.

The acoustic sensor 2870 is a piezoelectric sensor in some exemplary embodiments; however, the acoustic sensor 2870 is any other device type known to people having ordinary skill in the art, wherein the device is capable of detecting acoustic transmissions. The acoustic sensor 2870 detects acoustic transmissions formed in the adjacent rock formation 2906 when the indenter 2930 is pushed into the adjacent rock formation 2906 and cracks the adjacent rock formation 2906. The acoustic sensor 2870 converts the acoustic transmissions to a voltage signal, or other type of signal, so that the information can be recorded and subsequently analyzed pursuant to the descriptions previously provided. In certain exemplary embodiments, the signal from the acoustic sensor 2870 is sent to the surface of the wellbore 2808, either using a cable 2972 or wirelessly, so that the signal is analyzed. The acoustic sensor 2870 has a sensitivity range spanning from one to about 1,000 kilohertz. In certain exemplary embodiments, at least a portion of the acoustic sensor 2870 is positioned within the passageway 2931 of the indenter 2930 so that it is positioned closer to the cracks occurring in the adjacent rock formation 2906. However, in other exemplary embodiments, the acoustic sensor 2870 is positioned adjacent to, or near, the bottom end 2933 of the indenter 2930. In certain exemplary embodiments, the acoustic sensor 2870 is surrounded by a lubricant (not shown), similar to that described above. Although one type of acoustic sensor 2870 is described, alternative embodiments include other types of acoustic sensors capable of detecting cracks being initiated and propagated within the adjacent rock formation 2906.

The acoustic emission formation sampling tool 2900 is operated by being lowered into a wellbore 2908. The acoustic emission formation sampling tool 2900 is coupled to a drill

string (not shown) in some exemplary embodiments; while in others, the acoustic emission formation sampling tool 2900 is lowered into the wellbore 2908 using one or more cables (not shown). In the exemplary embodiments where the acoustic emission formation sampling tool 2900 is coupled to the drill string, the acoustic emission formation sampling tool 2900 rotates along with the rotation of the drill string. Once positioned at a desired depth within the wellbore 2908 for which properties of surrounding rock formations 2906 are to be determined, the acoustic emission formation sampling tool 2900 stops rotating, if it was rotating. The drive mechanism pushes one or more indenters 2930, and the one or more indenter guides 2920 according to some exemplary embodiments, into the surrounding rock formation 2906 at a minimum load. The drive mechanism pushing the indenter 2930 and the indenter guide 2920 is the same in some exemplary embodiments, while different in other exemplary embodiments. Also, one or more indenters 2930 operate simultaneously in certain exemplary embodiments, while in other exemplary embodiments, one or more indenters 2930 operate independently from one another at a different time. The drive mechanism increases the load that the indenter 2930 applies onto the surrounding rock formation 2906 over time until the drive mechanism reaches a maximum load that causes the indenter 2930 to exert this maximum load onto the surrounding rock formation 2906. Once the drive mechanism achieves the maximum load, the drive mechanism causes the indenter 2930, and the indenter guide 2920 according to some exemplary embodiments, to retract into the acoustic emission formation sampling tool 2900. The indenter 2930 causes the surrounding rock formation to initiate cracking at some intermediate load between the minimum load and the maximum load. This cracking generates acoustic transmissions which are received by the acoustic sensor 2870, which in turn transmits a signal to the surface. The signal is analyzed pursuant to the descriptions provided above, thereby determining one or more properties, including the CCS, of the rock formation at the desired depth within the wellbore 2908. Additionally, the values of the load that is applied to the rock formation 2906 is monitored, and optionally recorded.

It is expected that the indenter 2930 is capable of applying the appropriate loads onto the adjacent rock formations 2906 many times before being replaced or repaired due to damage. This repeated use of the indenter 2930 allows the operator to perform several tests within the same wellbore 2908 at various desired depth locations in the wellbore 2908. The acoustic emission formation sampling tool 2900, thereby, allows the operator to determine at least the confined compressive strength of the surrounding rock formation 2906 along the wellbore 2908 in situ.

FIG. 30 shows a top schematic view of an acoustic emission formation sampling tool 3000 in an operating position 3002 within a wellbore 2908 in accordance with another exemplary embodiment of the present invention. Referring to FIG. 30, the acoustic emission formation sampling tool 3000 includes a tool body 3010, a plurality of indenter guides 3020, a plurality of indenters 2930, and a plurality of acoustic sensors 2870. The acoustic emission formation sampling tool 3000 is similar to the acoustic emission formation sampling tool 2900 (FIG. 29) and includes additional components than those previously mentioned, such as one or more drive mechanisms. However, acoustic emission formation sampling tool 3000 is dissimilar to the acoustic emission formation sampling tool 2900 (FIG. 29) in that there are four indenter guides 3020A, 3020B, 3020C, and 3020D, four corresponding indenters 2930A, 2930B, 2930C, and 2930D, and four corresponding acoustic sensors 2870A, 2870B, 2870C,

and 2870D that are each positioned radially and equidistantly around the tool body 3010. Each indenter guide 3020 is similar to the indenter guide 2920 (FIG. 29). However, each indenter guide 3020 includes a flange 3021 that extends outwardly from a distal end 3024 of the indenter guide 3020. Each flange 3021 extends outwardly and arcuately to form about one-fourth of an outer surface 3012 of the tool body 3010 when the indenter guide 3020 is in a non-operating position, or retracted position. According to some exemplary embodiments, a first indenter guide 3020A, a second indenter guide 3020B, a third indenter guide 3020C, and a fourth indenter guide 3020D are positioned into the operating position 3002 at about the same time. The operating position 3002 is the position at which the indenter guide 3020 and/or the indenter 2930 is in engagement with the borehole wall 2909 of the borehole 2908. Thus, the indenter guides 3020 provide stability to the acoustic emission formation sampling tool 3000 when positioned in the operating position 2908. According to some of these exemplary embodiments, one of a first indenter 2930A, a second indenter 2930B, a third indenter 2930C, and a fourth indenter 2930D exerts a load onto the surrounding rock formation 2906 together with at least one other indenter 2930A, 2930B, 2930C, and 2930D. According to some other of these exemplary embodiments, each one of the first indenter 2930A, the second indenter 2930B, the third indenter 2930C, and the fourth indenter 2930D exerts a load onto the surrounding rock formation 2906 independently and at a different non-overlapping time period than any of the other indenters 2930A, 2930B, 2930C, and 2930D even though each of the indenter guides 3020A, 3020B, 3020C, and 3020D are in the operable position 3002. In alternative exemplary embodiments, indenter guides 3020A, 3020B, 3020C, and 3020D separated by about 180 degrees are positioned into the operating position 3002 at about the same time, thereby providing the stability to the acoustic emission formation sampling tool 3000. For example, the first and third indenter guides 3020A and 3020C are positioned into the operating position 3002 at about the same time, while second and fourth indenter guides 3020B and 3020D are positioned into the operating position 3002 at about the same time but at a different time period than the first and third indenter guides 3020A and 3020C. By performing the loading in a different non-overlapping time period, the cracks propagated by a loaded indenter 2930A can also be sensed and/or recorded by the sensors 2870B, 2870C, 2870D of one or more non-loaded indenters 2930B, 2930C, 2930D. The time lapse between the crack initiation sensed by the sensor 2870A in the loaded indenter 2930A and the crack initiation sensed by one or more unloaded sensors 2870B, 2870C, 2870D can provide a direct measurement of the density of the rock being sampled.

Each of the other components of the acoustic emission formation sampling tool 3000, whether mentioned above or not, such as the drive mechanism, is similar to the components of the acoustic emission formation sampling tool 2900 (FIG. 29), and therefore is not duplicatively described herein again for the sake of brevity. The acoustic emission formation sampling tool 3000 also operates in a similar manner as the operation of the acoustic emission formation sampling tool 2900 (FIG. 29) and is therefore not repeated again for the sake of brevity. The modifications applicable to the acoustic emission formation sampling tool 2900 (FIG. 29) also apply to the acoustic emission formation sampling tool 3000. For example, although four indenter guides 3020 are shown in the current exemplary embodiments, the number of indenter guides is greater or fewer in other exemplary embodiments. In one example, there are three indenter guides equidistantly and circumferentially separated by about 120 degrees.

FIG. 31 shows a side schematic view of an acoustic emission formation sampling tool 3100 in an operating position 3102 within a wellbore 2908 in accordance with another exemplary embodiment of the present invention. Referring to FIG. 31, the acoustic emission formation sampling tool 3100 includes a tool body 3110, a plurality of indenters 2930, a plurality of acoustic sensors 2870, and a pressure arm 3150. The acoustic emission formation sampling tool 3100 is similar to the acoustic emission formation sampling tool 2900 (FIG. 29) and includes additional components than those previously mentioned, such as one or more drive mechanisms described above. However, in certain exemplary embodiments, the acoustic emission formation sampling tool 3100 does not include the optional indenter guide (not shown).

The tool body 3110 is coupled, either directly or indirectly, to a drill string (not shown) according to some exemplary embodiments, while in other exemplary embodiments, the tool body 3110 is suspended into the wellbore 2908 using one or more cables (not shown). The tool body 3110 is cylindrically shaped and includes an outer surface 3112 which faces a borehole wall 2909 once the tool body 3110 is inserted into the wellbore 2908. The outer surface 3112 forms a plurality of cavities 3114 therein, which are arranged in a vertical and substantially linear array along at least a portion of the longitudinal length of the tool body 3110. Each cavity 3114 extends inwardly into the tool body 3110. Although four cavities 3114 are illustrated, there are greater or fewer cavities 3114 formed within the outer surface 3112 in other exemplary embodiments. Although one arrangement of the cavities 3114 is provided, the arrangement is different in other exemplary embodiments.

Each of the indenters 2930 are similar to the indenter 550 (FIG. 5) according to some exemplary embodiments. Each indenter 2930 is positioned within a respective cavity 3114 and is movable between a non-operating position (not shown) and the operating position 3102. In the operating position 3102, the indenter 2930 is at least partially positioned within the cavity 3114 and is pushing into the adjacent rock formation 2906 to exert a load onto the rock formation 2906. Conversely, in the non-operating position, the indenter 2930 is not pushing into the adjacent rock formation 2906. In certain exemplary embodiments, the indenter 2930 is entirely positioned within the corresponding cavity 3114. According to certain exemplary embodiments, the indenter 2930 moves in a substantially perpendicular direction with respect to the longitudinal length of the tool body 3110. However, according to other exemplary embodiments, the indenter 2930 moves in a substantially non-perpendicular direction with respect to the longitudinal length of the tool body 3110.

Each indenter 2930 is positioned from the non-operating position to the operating position 3102 and back to the non-operating position using a drive mechanism (not shown). The drive mechanism used for moving the indenter 2930 is within the purview of persons having ordinary skill in the art and having the benefit of the present disclosure. The drive mechanism used for moving one indenter 2930 is the same as the drive mechanism used for moving all the indenters 2930 in some exemplary embodiments. In other exemplary embodiments, the drive mechanism used for moving one indenter 2930 is different than the drive mechanism used for moving one or more of the remaining indenters 2930.

Although not illustrated, one or more seal rings (not shown), similar to the seal rings 2940 (FIG. 29), are positioned circumferentially around the indenter 2930 to provide a seal between the indenter 2930 and the portion of the tool body 3110 which defines the cavity 3114 according to certain exemplary embodiments. Thus, fluid and/or other contami-

nants present within the wellbore 2908 do not enter the tool body 3110 through movement of the indenter 2930 within the cavity 3114. The seal ring operates in a similar manner as described above.

The acoustic sensors 2870 are a piezoelectric sensor in some exemplary embodiments; however, the acoustic sensors 2870 are any other device type known to people having ordinary skill in the art, wherein the device is capable of detecting acoustic transmissions. The acoustic sensors 2870 detect acoustic transmissions formed in the adjacent rock formation 2906 when the indenter 2930 is pushed into the adjacent rock formation 2906 and cracks the adjacent rock formation 2906. The acoustic sensors 2870 convert the acoustic transmissions to a voltage signal, or other type of signal, so that the information can be recorded and subsequently analyzed pursuant to the descriptions previously provided. In certain exemplary embodiments, the signal from the acoustic sensors 2870 are sent to the surface of the wellbore 2908, either using a cable (not shown) or wirelessly, so that the signal is analyzed. The acoustic sensors 2870 have a sensitivity range spanning from one to about 1,000 kilohertz in certain exemplary embodiments. The acoustic sensors 2870 are positioned adjacent to the indenter 2930 in the manners as previously mentioned. In certain exemplary embodiments, the acoustic sensors 2870 are surrounded by a lubricant (not shown), similar to that described above. Although one type of acoustic sensor 2870 is described, alternative embodiments include other types of acoustic sensors capable of detecting cracks being initiated and propagated within the adjacent rock formation 2906.

The pressure arm 3150 is coupled to the tool body 3110 using a pivot pin 3152. The pressure arm 3150 is hydraulically operated to pivot around the pivot pin 3152 and move away from the tool body 3110 to position itself in an operating position 3103. The pressure arm 3150 is positioned to pivot away from the tool body 3150 in a direction that is opposite to the direction in which the cavities 3114, and hence also the indenters 2930, are facing. When desired, the pressure arm 3150 is hydraulically operated to pivot around the pivot pin 3152 and move towards the tool body 3110 to position itself in a non-operating position (not shown). This hydraulic operation is known to persons having ordinary skill in the art and is described in detail within U.S. Pat. No. 4,354,558, entitled "Apparatus and Drilling Method for Drilling into the Sidewall of a Drill Hole, and issued to Jageler et al. on Oct. 19, 1982, which has been incorporated by reference herein. Alternatively, other methods, such as an electric motor, is used to move the pressure arm 3150 in other exemplary embodiments. Although the pressure arm 3150 is described and illustrated, any other device capable of engaging and anchoring itself to a surface of the wellbore wall 2909 can be used in other exemplary embodiments.

The acoustic emission formation sampling tool 3100 is operated by being lowered into the wellbore 2908. The acoustic emission formation sampling tool 3100 is coupled to a drill string (not shown) in some exemplary embodiments; while in others, the acoustic emission formation sampling tool 3100 is lowered into the wellbore 2908 using one or more cables (not shown). In the exemplary embodiments where the acoustic emission formation sampling tool 3100 is coupled to the drill string, the acoustic emission formation sampling tool 3100 rotates along with the rotation of the drill string. Once positioned at a desired depth within the wellbore 2908 for which properties of surrounding rock formations 2906 are to be determined, the acoustic emission formation sampling tool 3100 stops rotating, if it was rotating. Once positioned at the desired depth, the pressure arm 3150 is pivoted around the pivot pin 3152 to engage with a surface 3108 of the wellbore

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wall 2909. The pressure arm 3150 continues to move away from the tool body 3110 causing the tool body 3110 to move toward an opposite surface 3109 of the wellbore wall 2909 until the tool body 3110 engages with the opposite surface 3109. The tool body 3150 is moved downward, either by applying a downward force or by allowing gravity to act upon the tool body 3110, thereby causing the pressure arm 3150 to dig into the surface 3108 of the wellbore wall 2909 and further anchor the tool body 3110 to the wellbore wall 2909.

Once the tool body 3110 is in contact with the opposite surface 3109 of the wellbore wall 2909, the drive mechanism pushes one or more indenters 2930 into the surrounding rock formation 2906 at a minimum load. One or more indenters 2930 operate simultaneously in certain exemplary embodiments, while in other exemplary embodiments, one or more indenters 2930 operate independently from one another at different times. The drive mechanism increases the load that the indenter 2930 applies onto the surrounding rock formation 2906 over time until the drive mechanism reaches a maximum load that causes the indenter 2930 to exert this maximum load onto the surrounding rock formation 2906. Once the drive mechanism achieves the maximum load, the drive mechanism causes the indenter 2930 to retract into the acoustic emission formation sampling tool 3100. The indenter 2930 causes the surrounding rock formation 2906 to initiate cracking at some intermediate load between the minimum load and the maximum load. This cracking generates acoustic transmissions which are received by the acoustic sensor 2870, which in turn transmits a signal to the surface. At loads above the intermediate load, the cracking continues to propagate through the rock formation 2906 and further generate additional acoustic transmissions. The signal from the acoustic sensor 2870 is analyzed pursuant to the descriptions provided above, thereby determining one or more properties, including the CCS, of the rock formation 2906 at the desired depth within the wellbore 2908. Additionally, the values of the load that is applied to the rock formation 2906 is monitored, and optionally recorded. Once the test has been completed, the tool body 3110 is raised to dislodge the pressure arm 3150 from the surface 3108 of the wellbore wall 2909 and then the pressure arm 3150 is pivotally moved into the non-operating position. The acoustic emission formation sampling tool 3100 is then moved to a different elevation within the wellbore 2908.

The positioning of the indenters 2930 within the acoustic emission formation sampling tool 3100 allows for variations within acoustic transmissions to occur over a vertical section of the wellbore 2908 when performing tests with the acoustic emission formation sampling tool 3100 being at a constant position within the wellbore 2908. Also, it is expected that the indenter 2930 is capable of applying the appropriate loads onto the adjacent rock formations 2906 many times before being replaced or repaired due to damage. This repeated use of the indenter 2930 allows the operator to perform several tests within the same wellbore 2908 at various desired depth locations in the wellbore 2908. The acoustic emission formation sampling tool 3100, thereby, allows the operator to determine at least the confined compressive strength of the surrounding rock formation 2906 along the wellbore 2908 in situ.

Although the indenters 2930 and the acoustic sensors 2870 are described as being installed within acoustic emission formation sampling tools 2900, 3000, and 3100, the indenters 2930 and the acoustic sensors 2870 can be used within other types of downhole tools, such as reamers, centralizers, and drill bits, without departing from the scope and spirit of the exemplary embodiment. Additionally, although the indenters

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2930 are installed within the downhole tool to provide a load onto the wellbore sidewall 2909, the indenters 2930 can be installed within the downhole tool to provide a load onto the bottom of the wellbore 2908. For example, the indenters 2930 is installed within the face of a bit in certain exemplary embodiments.

FIG. 32 illustrates a flowchart of a method 3200 for determining one or more properties of a rock formation located within a wellbore using the acoustic emission formation sampling tool in accordance with an exemplary embodiment of the present invention. Although certain steps are shown as proceeding in a particular order, the sequence of steps can be varied without departing from the scope and spirit of the exemplary embodiment. Also, although certain functions are performed in one or more steps, the number of steps for performing that function can be increased or decreased without departing from the scope and spirit of the exemplary embodiment.

Referring to FIG. 32, at step 3205, the method 3200 starts. From step 3205, method 3200 proceeds to step 3210. At step 3210, an acoustic formation sampling tool, similar to any of the described embodiments above, is positioned within a wellbore at a depth of interest. Upon completion of step 3210, method 3200 proceeds to step 3220. At step 3220, at least one indenter of the acoustic formation sampling tool is engaged to a portion of a rock formation surrounding at least a portion of the wellbore. Upon completion of step 3220, method 3200 proceeds to step 3230. At step 3230, one or more cracks are created in the rock formation when a load is exerted onto the indenter. The cracks form one or more acoustic events. Upon completion of step 3230, method 3200 proceeds to step 3240. At step 3240, a sensor senses the acoustic events that formed as the indenter is loaded into the rock formation. Upon completion of step 3240, method 3200 proceeds to step 3250. At step 3250, one or more properties of the rock formation is determined from the acoustic events. Upon completion of step 3250, method 3200 proceeds to step 3260. At step 3260, the determined rock property of the rock formation is provided as an input into one or more of a hydraulic fracturing program, a perforation program, a drilling program, a liner program, or a completion program. Each of these program types an use of these program types are known to persons having ordinary skill in the art having the benefit of the present disclosure and therefore is not described for the sake of brevity. After step 3260, method 3200 proceeds to step 3265 where method 3200 is stopped.

Although each exemplary embodiment has been described in detail, it is to be construed that any features and modifications that are applicable to one embodiment are also applicable to the other embodiments. Furthermore, although the invention has been described with reference to specific embodiments, these descriptions are not meant to be construed in a limiting sense. Various modifications of the disclosed embodiments, as well as alternative embodiments of the invention will become apparent to persons of ordinary skill in the art upon reference to the description of the exemplary embodiments. It should be appreciated by those of ordinary skill in the art that the conception and the specific embodiments disclosed may be readily utilized as a basis for modifying or designing other structures or methods for carrying out the same purposes of the invention. It should also be realized by those of ordinary skill in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims. It is therefore, contemplated that the claims will cover any such modifications or embodiments that fall within the scope of the invention.

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What is claimed is:

1. A downhole acoustic emission testing system, comprising:

a drill string extending into a wellbore surrounded by a rock formation; and

a downhole tool coupled to the drill string and positioned within the wellbore, the downhole tool, comprising:

a tool body comprising an outer surface defining one or more cavities therein, the cavity extending into the tool body;

one or more indenters, each indenter positioned within a corresponding cavity, each indenter positionable into an operating position and a non-operating position; and

one or more acoustic sensors positioned within the cavity and adjacent to the indenter,

wherein the indenter is applying a load onto the rock formation when in the operating position, the load ranging between a minimum load and a maximum load, and

wherein the acoustic sensor senses one or more acoustic events occurring within the rock formation when the indenter is in the operating position.

2. The downhole acoustic emission testing system of claim 1, wherein the acoustic sensor receives the acoustic events and transmits one or more signals corresponding to each acoustic event.

3. The downhole acoustic emission testing system of claim 1, wherein the tool body comprises a substantially longitudinal cylindrical shape and wherein the indenters move substantially perpendicularly with respect to the length of the tool body.

4. The downhole acoustic emission testing system of claim 1, wherein at least a portion of the indenter comprises polycrystalline diamond compact.

5. The downhole acoustic emission testing system of claim 1, wherein the indenters are positioned circumferentially around the tool body.

6. The downhole acoustic emission testing system of claim 1, wherein the indenters are aligned vertically in a substantially linear array along the tool body.

7. The downhole acoustic emission testing system of claim 1, wherein the downhole tool further comprises a pressure arm pivotally coupled to the tool body, the pressure arm pivotally moving away from the tool body in a direction opposite from the positioning of the indenters.

8. The downhole acoustic emission testing system of claim 1, wherein the downhole tool further comprises one or more indenter guides that form a channel therein, at least a portion of each indenter guide positioned within the cavity, the indenter guide positionable between a second operating position and a second non-operating position, the indenter guide extending away from the tool body when in the second oper-

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ating position, and wherein the indenter is positioned within the channel of the indenter guide.

9. A method for testing a rock formation surrounding a wellbore, comprising:

inserting a downhole tool into a wellbore surrounded by a rock formation, the downhole tool, comprising:

a tool body comprising an outer surface defining one or more cavities therein, the cavity extending into the tool body;

one or more indenters, each indenter movably positioned at least partially within a corresponding cavity, each indenter positionable into an operating position and a non-operating position; and

one or more acoustic sensors positioned within the cavity and adjacent to the indenter,

positioning one or more indenters in contact with the rock formation;

applying a load onto the indenter thereby supplying the load onto the rock formation;

generating one or more acoustic events within the rock formation; and

detecting the one or more acoustic events.

10. The method of claim 9, wherein the load ranges from a minimum load to a maximum load, the load progressively increasing over time.

11. The method of claim 9, wherein the tool body comprises a substantially longitudinal cylindrical shape and wherein the indenters move substantially perpendicularly with respect to the length of the tool body.

12. The method of claim 9, wherein the indenters are positioned circumferentially around the tool body.

13. The method of claim 9, wherein the indenters are aligned vertically in a substantially linear array along the tool body.

14. The method of claim 9, wherein positioning one or more indenters in contact with the rock formation comprises moving the tool body adjacent to the rock formation.

15. The method of claim 9, wherein positioning one or more indenters in contact with the rock formation comprises moving at least a portion of the outer surface of the tool body that forms the cavity adjacent to the rock formation.

16. The method of claim 9, further comprising determining the confined compressive strength of the rock formation exposed to the indenter from the one or more acoustic events without removing the downhole tool from the wellbore.

17. The method of claim 9, further comprising determining one or more properties of the rock formation without removing the downhole tool from the wellbore and inputting the one or more properties of the rock formation into one or more of a hydraulic fracturing program, a perforation program, a drilling program, a liner design, and a completion program.

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